THE UNIVERSITY OF MICHIGAN
JAN 23 1962
ENGINEERING LIBRARY

Journal

of

THE ROYAL AERONAUTICAL SOCIETY

DECEMBER 1961

CONTENTS

NOTICES

RESEARCHES IN SPACE FLIGHT TECHNOLOGY —THE 49th WILBUR WRIGHT MEMORIAL LECTURE — A. SILVERSTEIN

BIRD FLIGHT AND THE AEROPLANE — J. WILDING

THE DEVELOPMENT OF TAILLESS AIRCRAFT AND FLYING WINGS — W. BISHOP

GLIDING AND MAN POWERED FLIGHT — L. WELCH

THE HELICOPTER; THE FIRST OF THE VTOL AIRCRAFT — R. HAFNER

TECHNICAL NOTES

Augmenting Aerodynamic Lift with Jet Lift—P. D. ARTHUR and E. T. PITKIN. The Stability of a Thin Cantilever Beam under an Articulated Tip Load—B. SARAVANOS. Optimum Support Position for Flat Plate Subjected to Pressure—R. KITCHING.

EIGHTH ANGLO-AMERICAN AERONAUTICAL CONFERENCE

THE BRANCHES

GRADUATES' AND STUDENTS' SECTION

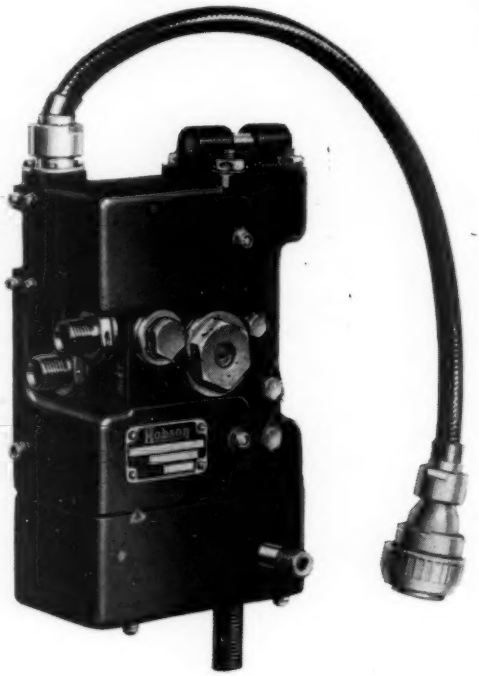
THE LIBRARY — REVIEWS — REPORTS

INDEX TO VOLUME 65, 1961

TWELVE SHILLINGS AND SIXPENCE MONTHLY

4 HAMILTON PLACE LONDON W1

ELECTRO-HYDRAULIC ACTUATION FOR AUTO-CONTROL AND STABILISATION



Shown above is an example of a self-contained electro-hydraulic autopilot/auto-stabiliser actuator. The principles and mechanisms embodied in its design are also employed by Hobsons in powered flying controls incorporating high performance integrated electro-hydraulic servo actuation.

In the design of HOBSON ELECTRO-HYDRAULIC ACTUATORS reliability has been given precedence over features providing a very large power gain.

In a servo loop comprising amplifier, actuator and feed back device, the required overall loop gain can, in theory, be distributed at will between amplifier and actuator.

At one time, limited amplifier performance led to the design of delicate electro-hydraulic valves capable of responding to minute amplifier outputs. The performance available from the present transistor amplifiers permits the use of a more robust mechanism, avoiding small operating forces and metering orifices and yet meeting all modern aircraft and missile response requirements including those at small amplitudes.

No special filteration requirements are imposed by Hobson servo valves although, as in other hydraulic mechanisms, a good standard of cleanliness prolongs life.

HOBSON ELECTRO-HYDRAULIC ACTUATORS are in widespread use and have the highest possible reputation for reliability.

Hobson

DESIGNERS AND MANUFACTURERS OF PRECISION-ENGINEERED EQUIPMENT FOR THE AIRCRAFT INDUSTRY

H. M. HOBSON LIMITED · FORDHOUSES · WOLVERHAMPTON

Journal of
THE ROYAL AERONAUTICAL SOCIETY

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

PUBLISHED MONTHLY AT

4 HAMILTON PLACE, LONDON, W.1

Telephone: Grosvenor 3515-9 *Telegrams*: Didaskalos, London, W.1.

SUBSCRIPTIONS: £7 10s. 0d. PER ANNUM, PLUS 9s. POSTAGE AND PACKING

SINGLE COPIES: 12s. 6d. PLUS 9d. POSTAGE AND PACKING

VOLUME 65 DECEMBER 1961 NUMBER 612

CONTENTS

		PAGE
Notices Third I.C.A.S. Congress: Stockholm—Acknowledgments—Lecture Theatre Appeal—Christmas 1961—Air Law Group—New Fellows—Membership Subscriptions—Microfilm Editions of the Journal and Quarterly—Diary—Symposium on the Mathematical Theory of Automata—Presentation of Honours and Awards 1961—Supplement to the Oxford English Dictionary—News of Members—Elections—Lecture Summaries.		LI
Researches in Space Flight Technology—The 49th Wilbur Wright Memorial Lecture	A. SILVERSTEIN	779
Bird Flight and the Aeroplane	J. WILDING	796
The Development of Tailless Aircraft and Flying Wings	W. BISHOP	799
Gliding and Man Powered Flight	L. WELCH	807
The Helicopter; the First of the VTOL Aircraft	R. HAFNER	815
Technical Notes Augmenting Aerodynamic Lift with Jet Lift—P. D. ARTHUR and E. T. PITKIN. The Stability of a Thin Cantilever Beam under an Articulated Tip Load—B. SARAVANOS. Optimum Support Position for Flat Plate Subjected to Pressure—R. KITCHING.		830
Eighth Anglo-American Aeronautical Conference		838
The Branches		842
Graduates' and Students' Section		843
The Library REVIEWS: Long-Range Ballistic Missiles—The Conquest of Space—Atlas of the Other Side of the Moon—Science in Space—Fatigue Testing and Analysis of Results—My Polar Flights—The Aces—The Forgotten Ones, The Story of the Ground Crews—Wings on My Sleeve—Beyond the Planet Earth. ADDITIONS TO THE LIBRARY. REPORTS.		844
Index to Volume 65, 1961		853

All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

ADVERTISEMENT OFFICE: *Oxford House, 15 Crosswall, London E.C.3. Royal 7768.*

PRINTED BY THE LEWES PRESS, WIGHTMAN & CO. LTD., LEWES, SUSSEX, ENGLAND, AND PUBLISHED BY THE ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, LONDON W.1, ENGLAND

THE ROYAL AERONAUTICAL SOCIETY

OVERSEAS DIVISIONS

AUSTRALIA
President: R. J. IFIELD, F.R.Ae.S.
Hon. Secretary: W. ISBISTER, [A.F.R.Ae.S.
Science House,
Gloucester & Essex Streets,
Sydney, New South Wales.

Branches at:
Sydney, Melbourne, Adelaide.

NEW ZEALAND
President: A. J. SMAILL, A.F.R.Ae.S.
Hon. Secretary: T. T. N. COLERIDGE, [A.F.R.Ae.S.
The Shell Company
of New Zealand Ltd.,
Box 2091, Wellington.

Branches at: Auckland, Wellington, Palmerston North, Christchurch.

SOUTHERN AFRICA
President: PROFESSOR S. SMOLENSIC, A.F.R.Ae.S.
Hon. Secretary: Mrs. D. D. HUGHES, 14 Keyes Court, Keyes Avenue, Rosebank, Johannesburg.

Branches at:
Durban and Salisbury.

OVERSEAS BRANCH

SINGAPORE *Chairman:* E. A. CRABBE, A.F.R.Ae.S.
Hon. Secretary: T. C. CHIOLE, A.R.Ae.S., c/o Malayan Airways, Paya Lebar Airport, Singapore.

BRANCHES IN THE UNITED KINGDOM

BELFAST
President: D. KEITH-LUCAS, F.R.Ae.S.
Chairman: S. J. SEALEY, A.F.R.Ae.S.
Hon. Secretary: C. N. ROBERTS, c/o Short Brothers & Harland Ltd., Precision Engineering Division, Montgomery Road, Castlereagh, Belfast 6.

BIRMINGHAM AND WOLVERHAMPTON
President: L. S. GREENLAND, F.R.Ae.S.
Chairman: Dr. L. W. J. NEWMAN, A.F.R.Ae.S.
Hon. Secretary: A. JAMES, A.F.R.Ae.S., Braeside, Bacon's End, Coleshill, Warwicks.

BOSCOMBE DOWN
President: Air Cdre. J. F. ROULSTON, C.B.E., D.S.O., D.F.C.
Chairman: Dr. D. CAMERON, F.R.Ae.S.
Hon. Secretary: Sqn. Ldr. H. H. HORSHAM, M.B.E., A.R.Ae.S., A. & A.E.E., Boscombe Down, Amesbury, Wilts.

BRISTOL
President: R. HAFNER, F.R.Ae.S.
Chairman: D. J. FARRAR, F.R.Ae.S.
Hon. Secretary: W. O. LEE, A.R.Ae.S. Bristol Aircraft Ltd., Filton, Bristol Glos.

BROUGH
President: N. E. ROWE, C.B.E., F.R.Ae.S.
Chairman: B. P. LAIGHT, F.R.Ae.S.
Hon. Secretary: A. D. HOWARTH, A.R.Ae.S., Blackburn Aircraft Ltd., Brough, Yorks.

CAMBRIDGE
President: Professor W. A. MAIR, F.R.Ae.S.
Chairman: R. O. GATES, A.F.R.Ae.S.
Hon. Secretary: E. M. J. SCHAFFTER, A.F.R.Ae.S., Marshalls' Flying School Ltd., Newmarket Road, Cambridge.

CHESTER
President: C. B. V. NEILSON, A.F.R.Ae.S.
Chairman: L. C. WHITELEY, A.F.R.Ae.S.
Hon. Secretary: J. WHITTLE, Thornton Research Centre, P.O. Box 1, Chester.

CHRISTCHURCH
President: E. W. J. GRAY, F.R.Ae.S.
Chairman: H. E. VINCENT, A.F.R.Ae.S.
Hon. Secretary: N. J. KENT, A.R.Ae.S., c/o Vickers-Armstrongs (Aircraft) Ltd., Hurn Airport, Christchurch.

COVENTRY
President: H. M. WOODHAMS, C.B.E., F.R.Ae.S.
Chairman: C. BAYLY, F.R.Ae.S.
Hon. Secretary: J. G. LUM, Sir W. G. Armstrong Whitworth Aircraft Ltd., Whitley, Coventry.

DERBY
President: J. D. PEARSON, F.R.Ae.S.
Chairman: A. A. RUBBRA, F.R.Ae.S.
Hon. Secretary: J. H. STEPHENS, A.F.R.Ae.S., c/o Rolls-Royce Ltd., Nightingale Road, Derby.

GLASGOW
President: Dr. A. W. BABISTER, A.F.R.Ae.S.
Chairman: Ir. B. J. G. ASBEEK BRUSSE, A.F.R.Ae.S.
Hon. Secretary: W. N. ALCOCK, Shenstone, Dumbuck Crescent, Dumbarton.

GLOUCESTER AND CHELTENHAM
President: R. W. WALKER, F.R.Ae.S.
Chairman: J. G. RUSSELL, A.F.R.Ae.S.
Hon. Secretary: C. E. HUTT, A.R.Ae.S. c/o S. Smith and Sons (England) Ltd., Bishops Cleeve, nr. Cheltenham, Glos.

HALTON
President: Air Marshal Sir HERBERT SPRECKLEY, K.B.E., C.B., F.R.Ae.S.
Chairman: Air Cdre. T. N. COSLETT, C.B., O.B.E.
Hon. Secretary: Sqn. Ldr. J. W. G. PARKER, E. & I. Squadron, R.A.F. Halton, Bucks.

HATFIELD
President: Sir GEOFFREY DE HAVILLAND, C.B.E., A.F.C., Hon.F.R.Ae.S.
Chairman: D. R. NEWMAN, A.F.R.Ae.S.
Hon. Secretary: A. A. FAWCETT, A.R.Ae.S., de Havilland Aircraft Ltd., Hatfield, Herts.

HENLOW
President: D. E. MORRIS, F.R.Ae.S.
Chairman: Wg. Cdr. E. J. HOLDEN, M.B.E., A.F.R.Ae.S.
Hon. Secretary: Sqn. Ldr. A. H. CRAVEN, A.F.R.Ae.S., Officers' Mess, R.A.F. Technical College, Henlow, Beds.

ISLE OF WIGHT
President: Sir ARTHUR GOUGE, Hon. F.R.Ae.S.
Chairman: R. STANTON-JONES, A.F.R.Ae.S.
Hon. Secretary: R. L. WHEELER, A.F.R.Ae.S., Design Office, Saunders-Roe Ltd., Osborne, Isle of Wight.

LEICESTER
Chairman: K. B. AYERS, A.F.R.Ae.S.
Hon. Secretary: M. G. RUSSELL, A.R.Ae.S., c/o Design Office, Auster Aircraft Ltd., Rearsby, Leics.

LONDON AIRPORT
President: Rear Admiral Sir MATTHEW S. SLATTERY, K.B.E., C.B., F.R.Ae.S.
Chairman: C. ABELL, O.B.E., F.R.Ae.S.
Hon. Secretary: N. BROWN, A.R.Ae.S., B.O.A.C. H.Q., London Airport, Middlesex.

LUTON
President: C. L. COWDREY, F.R.Ae.S.
Chairman: E. M. DOWLEN, A.F.R.Ae.S.
Hon. Secretary: L. A. WILLOTT, A.F.R.Ae.S., Hunting Aircraft Ltd., The Airport, Luton, Beds.

MANCHESTER
President: C. E. FIELDING, O.B.E. F.R.Ae.S.
Chairman: A. STEWART, A.F.R.Ae.S.
Hon. Secretary: J. A. E. WATERFALL, 56 Manor Avenue, Ashton-on-Mersey, Cheshire.

MERTHYR AND TREFOREST
President: C. E. MCGIBBON.
Chairman: J. INGRAM.
Hon. Secretary: Dr. G. O. FORESTER, Chief of Research, Teddington Aircraft Controls Ltd., Cefn Coed, nr. Merthyr Tydfil, South Wales.

PRESTON
President: Lord NELSON OF STAFFORD.
Chairman: T. O. WILLIAMS.
Hon. Secretary: J. F. FOSS, A.F.R.Ae.S., English Electric Aviation Ltd., Warton Aerodrome, nr. Preston, Lancs.

READING
President: Sir FREDERICK HANDLEY PAGE, C.B.E., Hon.F.R.Ae.S.
Chairman: R. W. HILKEN, A.F.R.Ae.S.
Hon. Secretary: R. BRAY, A.R.Ae.S., Handley Page (Reading) Ltd., The Aerodrome, Woodley, Reading, Berks.

SOUTHAMPTON
Chairman: Professor E. J. RICHARDS, O.B.E., F.R.Ae.S.
Hon. Secretary: F. C. KIRKPATRICK, A.R.Ae.S., Folland Aircraft Ltd., Hamble, Southampton, Hants.

SOUTHEND
President: F. A. LAKER, A.R.Ae.S.
Chairman: T. R. C. BERRETT, A.R.Ae.S.

SWINDON
President: S. R. HUGHES, A.F.R.Ae.S.
Chairman: G. KEEN, A.F.R.Ae.S.
Hon. Secretary: D. RIGG, A.R.Ae.S., Vickers-Armstrongs (Aircraft) Ltd., Supermarine Works, South Marston, Swindon, Wilts.

WEYBRIDGE
President: Sir GEORGE EDWARDS, C.B.E., Hon.F.R.Ae.S.
Chairman: H. H. GARDNER, F.R.Ae.S.
Hon. Secretary: E. G. BARBER, [A.F.R.Ae.S.
Vickers-Armstrongs (Aircraft) Ltd., Weybridge, Surrey.

YEOVIL
President: E. C. WHEELDON.
Chairmen: D. L. HOLLIS WILLIAMS, F.R.Ae.S. and Dr. E. W. STILL, F.R.Ae.S.
Hon. Secretary: L. A. LANSDOWN, A.F.R.Ae.S., Westland Aircraft Ltd., Yeovil, Somerset.

NOTICES

Third ICAS Congress—Stockholm

The Third Congress of the International Council of the Aeronautical Sciences (ICAS) will be held in the New Congress Hall (Folkets Hus) Stockholm, from 27th August to 1st September 1962.

Approximately 50 specialised papers and six general lectures are to be given in the following subject areas: 1. Physics of the Upper Atmosphere; 2. Electronics; 3. Materials and Fatigue; 4. Boundary Layer Transition; 5. VTOL-STOL; 6. Supersonic and Hypersonic Aerodynamics; 7. Structures at High Temperature and Aerothermoelasticity; 8. Supersonic Transport Aircraft; 9. Hypersonic Flight at Very High Altitude.

The Technical Programme is being arranged so as to permit ample time for discussion and with the co-operation of the authors, the Arrangements Committee—which is under the chairmanship of Mr. Bengt Reistad of the Aeronautical Research Institute of Sweden—intends to have preprints available for distribution before the Congress opens.

Application forms for registration and for hotel registration will be available to members from the Society in January 1962.

Acknowledgments

The Council wish to thank sincerely the following people for their presentations to the Library:—

J. P. Herriot, of Rolls-Royce Ltd., for three early engine handbooks.

The Librarian of Kensington Public Libraries for a post card "thrown out of Mr. J. L. Tannar's 'Mammoth' balloon in the *Daily Graphic* Expedition and forwarded to the addressee from Mellerud, Sweden".

Flight Lt. J. D. Penrose (*Graduate*) for a copy of the Air Department publication "Truing up of Aeroplanes" (1916).

Lecture Theatre Appeal

The Fund has now reached a Grand Total of £108,840 0s. 0d.*, which figure approximates to the estimated final cost according to the Architects' best information at the present time. However, as the result of experience gained during the first year's working, certain modifications have been put in hand and some additional expenditure may have to be met. Similarly, it has become necessary to purchase small items of equipment to improve the amenities of the building.

It is therefore considered prudent to keep the fund open for the present, and all donations will be most welcome. The following contributions received since the publication of the previous list are gratefully acknowledged.

Donations	£	s.	d.
Anonymous	2	11	2
R. J. Atkinson, Esq.	10	0	0
Australian Division	105	0	0
F. S. Bhinder, Esq.	3	11	0
A. E. Clifford, Esq. (Additional) ...	12	0	0
R. E. Cunningham, Esq.	1	1	0
R. M. Dakin, Esq. (Additional) ...	2	0	0
Docker Brothers (Additional) ...	29	18	6
Wing Cdr. W. Goodridge	2	2	0
H. D. Hoekstra, Esq.	3	3	0
Sqn. Ldr. D. C. H. Owen	5	0	0
A. A. Rose, Esq.	5	0	0
H. T. Tremelling, Esq.	1	1	0

**This figure of £108,840 0s. 0d. is less than that previously published since certain promises and "donations in kind" have not materialised for various reasons and have been eliminated from the total.*

Christmas 1961

The President, Council and Staff of the Society send to all Members at home and overseas their good wishes for a Happy Christmas.

Air Law Group

The Council of the Society has now approved the formation of an Air Law Group with the following principal objectives:—

1. To promote the establishment and co-ordination of facilities for the objective study and evolution of law applicable to aeronautics and astronautics.
2. To provide facilities for the collaboration of all members who may be able to contribute to such studies, and to collaborate with other persons or organisations with similar interests.
3. To undertake, upon request, the constructive analysis of proposed legislation, and of draft international agreements or conventions.
4. To disseminate information and ideas among members consistent with the aims of the Group.
5. To ensure that each member acts in an individual capacity and not in a capacity representative of any political, commercial, professional, trades union or other sectional interest.

A Steering Committee is being formed to discuss the future programme of the Group, and details will be issued later.

Those wishing to join the Group are invited to communicate with The Secretary, Royal Aeronautical Society, 4 Hamilton Place, London, W.1.

New Fellows

The following have been elected to Fellowship:—

Peter Charles Cleaver, Group Captain, Plans, H.Q. Maintenance Command, R.A.F., Andover.

Ralph Butterworth Lightfoot, Chief Engineer, Sikorsky Aircraft, Div. of United Aircraft Corp., U.S.A.

Michael James Lighthill, Director, Royal Aircraft Establishment, Farnborough.

Igor Alexis Sikorsky, Chief Aerodynamicist, Sikorsky Aircraft, Div. of United Aircraft Corp., U.S.A.

Peter Latham Sutcliffe, Chief Technician, Advanced Projects Group, Hawker Siddeley Aviation Ltd., Kingston.

Membership Subscriptions 1962

For the convenience of members it has been decided to issue reminders to those resident in the United Kingdom approximately one month before the 1962 subscriptions become due on 1st January next. This new form has been designed to incorporate the various notes previously published in the Journal, but overseas members will continue to receive their individual reminders in the previous manner.

Microfilm Editions of the Journal and Quarterly

Microfilm copies of the 1957, 1959 and 1960 Journal and of the 1959 and 1960 Aeronautical Quarterly are now available from University Microfilms Ltd., 44 Great Queen Street, London, W.C.2.

A complete year of the Journal is filmed on 35 mm. unperforated microfile film and is accommodated on one 100 ft. reel measuring 4 in. × 4 in. × 1½ in. (24 cubic inches). The cost of one year's microfilm edition of the Journal is approximately £1 15s. 9d.

The Aeronautical Quarterly is also on one reel per year with the same dimensions as the Journal reel. The cost for one year's edition is 17s. 6d.

These microfilm editions are available only to members or subscribers to the Journal or to the Quarterly.

DIARY

MAIN SOCIETY

All lectures in London will be held in the Lecture Theatre, 4 Hamilton Place, unless otherwise stated.

13th December
MAIN LECTURE AT THE MANCHESTER BRANCH—Air Lines' Approach to Aircraft Selection. R. Nivet. Reynolds Hall, College of Technology, Manchester. 7 p.m.

4th January
YOUNG PEOPLE'S LECTURE—Air Liners of the Future. G. H. Lee. 3 p.m.

29th January
Joint Discussion with the Institution of Electrical Engineers. Automatic Maintenance Testing. To be opened by P. Hearne, H. Fuchs and A. H. Stewart. 6 p.m. (Tea at 5.30 p.m.)

AGRICULTURAL AVIATION GROUP

13th December
All-day Symposium on the Uses of the Aeroplane in Agriculture (*see* special notice in the November JOURNAL).

ASTRONAUTICS AND GUIDED FLIGHT SECTION

12th December
Military Design Requirements of Guided Missiles. E. W. Denison. 6 p.m.

16th January
Development of Seaslug. C. Bayly and A. Lightbody. 6 p.m.

GRADUATES' AND STUDENTS' SECTION

24th January
The New Bluebird. K. W. Norris. 7 p.m.

HISTORICAL GROUP

15th January
R.101 and other Airships. Sir Harold Roxbee Cox. 6 p.m.

MAN POWERED AIRCRAFT GROUP

15th December
Problems of a Man Powered Rotorcraft. R. A. Graves. 6 p.m.

26th January
Design Philosophy of Man Powered Aircraft. J. J. Spillman. 6 p.m.

ROTORCRAFT SECTION

5th January
Rotating Aerofoils and Flaps. S. Neumark. 6 p.m.

BRANCHES

11th December
Boscombe Down—Members' Meeting (Junior Members' lecture competition). Lecture Hall, A. & E. E. 5.30 p.m.
Henlow—Rebuilding and Flying Historic Aircraft. A. H. Wheeler. Assembly Hall, R.A.F. Technical College, Henlow. 7.45 p.m.

12th December
Luton—707 Operation. H. L. Fry. The Napier Senior Staff Canteen, Luton Airport. 6 p.m.

13th December
Chester—Mechanical Handling Equipment. Lecturer from Conveyancer Fork Trucks Ltd. Lecture Theatre, Grosvenor Museum, Chester. 7.30 p.m.
Christchurch—Film Show. Antarctic Crossing. Sir Vivian Fuchs. King's Arms Hotel. 7.30 p.m.
Luton—Schools' Lecture: How an Aircraft is Built. F. W. Buglass. Luton Technical School. 2.30 p.m.
Reading and District—Making Aircraft Films. G. M. Shipway. Western Manufacturing (Reading) Ltd. 6.15 p.m.
Southampton—Pioneering Aeronautical Development in Brazil. K. L. C. Legg. Engineering Lecture Theatre, University of Southampton. 8 p.m.

14th December
Cheltenham—New Developments in Aircraft Propulsion. S. G. Hooker. St. Mary's College, The Park. 7.30 p.m.
Coventry—Junior Lecures and Films. Herbert Art Gallery, Coventry. 7.30 p.m.
Isle of Wight—Annual General Meeting and Film Show. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, East Cowes. 6 p.m.

15th December
Weybridge—Annual Dance. St. George's Hill Lawn Tennis Club, Weybridge. 9 p.m.

19th December
Glasgow—The Place of Wind Tunnel Research in the Development of a New Aeroplane. Ir. B. J. G. Asbeek Brusse. Glasgow University, W.2. 7.15 p.m.

3rd January
Brough—Model Testing in the A.R.A. Wind Tunnel. R. Hills. Royal Station Hotel, Brough. 7.30 p.m.
Christchurch—Analysis of Yacht Performance. P. R. Crewe. King's Arms Hotel. 7.30 p.m.
Reading and District—A Non-Technical Explanation of Contemporary Radio Navigation Aids and Radio Communications. K. W. B. Fonweather. Western Manufacturing (Reading) Ltd. 6.15 p.m.
Swindon—Research at the College of Aeronautics. A. J. Murphy. The College, Victoria Road, Swindon. 7.30 p.m.

4th January
Southampton—The Aircraft Industry in 1962. E. C. Bowyer. Cinema-College of Air Training Hamble. 8 p.m.

9th January
Luton—Agricultural Aviation. A. H. Wheeler. Napier Senior Staff Canteen, Luton Airport. 6 p.m.

10th January
Bristol—Mathematics and Aeronautics. M. J. Lighthill. Main Lecture Theatre, University Engineering Laboratories, University Walk, University of Bristol. 7 p.m.
Chester—Radio Astronomy. R. G. Davies. Lecture Theatre, Grosvenor Museum, Chester. 7.30 p.m.

11th January
Isle of Wight—History of the Schneider Trophy Races. W. Cox. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, East Cowes. 6 p.m.
London Airport—Brains Trust. Team: Sir M. Slattery, P. Cane, R. E. Hardingham, H. Conway. Chairman: B. S. Shenstone. (Questions of general aeronautical interest to Secretary by 6th January). Senior Mess, 4th Floor, B.O.A.C. H.Q., London Airport. 6 p.m.

15th January
Henlow—Joint Meeting with the Institution of Mechanical Engineers. Aircraft Design Philosophy. F. H. Robertson. Assembly Hall, R.A.F. Technical College. 7.45 p.m.

17th January
Cheltenham—Hovercraft. G. C. Keen. St. Mary's College, The Park. 7.30 p.m.
Coventry—Joint R.Ae.S./I.E.E. Lecture. New Ideas in Aircraft Electrical Systems. M. Hancock. Herbert Art Gallery, Coventry. 7.30 p.m.

18th January
Birmingham and Wolverhampton—Space Communication. G. K. Pardoe. Assembly Room, Bing Kenrick Suite, College of Technology, Birmingham. 7.15 p.m.
Cambridge—Airships. T. P. Yorke-Moore. No .1 Lecture Hall, Cambridge University Engineering Laboratories. 8.15 p.m.

22nd January
Glasgow—Graduates' and Students' Section—Repair of Aircraft in the Field. J. Logan. Scottish Aviation Ltd., Prestwick. 7.30 p.m.

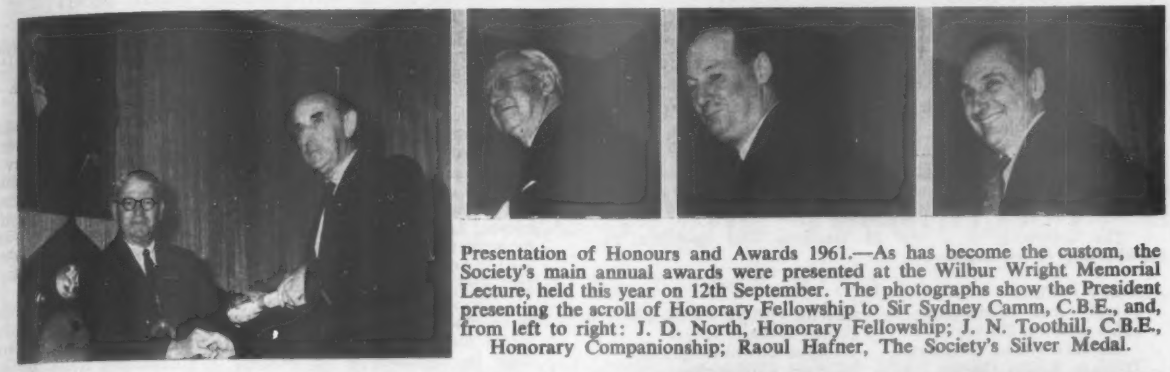
24th January
Reading and District—Modern Model Testing. W. A. Crago. Lecture Theatre, Reading Technical College. 7.15 p.m.

25th January
Bristol—History of German Guided Missiles. H. M. Mayer. Conference Room, Filton House, Bristol Aircraft Ltd., Filton. 6 p.m.
Weybridge—The Experimental Investigation of Space. J. A. Ratcliffe. Apprentice Training School, Vickers-Armstrong (Aircraft) Ltd., Weybridge. 5.45 p.m.

SYMPOSIUM ON THE MATHEMATICAL THEORY OF AUTOMATA

The twelfth annual international Polytechnic Institute of Brooklyn Symposium will be held in New York City from 24th-26th April 1962 in co-operation with the Institute of Radio Engineers, the American Institute of Electrical Engineers and the U.S. Defense Research Agencies. The Symposium will be devoted to "The Mathematical Theory of Automata" and emphasise the application of mathematical techniques to information systems. The closing date for submission of contributed papers or 200-word abstracts is 5th January. Proposed topics are:—

1. Computability, classes of Turing machines and automata, unsolvable problems, problem complexity.
2. Symbolic logic, methods for programming logical



Presentation of Honours and Awards 1961.—As has become the custom, the Society's main annual awards were presented at the Wilbur Wright Memorial Lecture, held this year on 12th September. The photographs show the President presenting the scroll of Honorary Fellowship to Sir Sydney Camm, C.B.E., and, from left to right: J. D. North, Honorary Fellowship; J. N. Toothill, C.B.E., Honorary Companionship; Raoul Hafner, The Society's Silver Medal.

Second row.—Lionel Haworth, O.B.E., The Society's Bronze Medal; Dr. S. G. Hooker, O.B.E., British Gold Medal; Pierre Satre, British Silver Medal; Dr. E. Eastwood, Wakefield Gold Medal.

Third row.—R. P. Dickinson, R. P. Alston Medal; J. Wilding, N. E. Rowe Medal (21-26 years of age group); W. Bishop, N. E. Rowe Medal (under 21 years group); Jack Brannon, Alan Marsh Medal; M. S. Eden, Alan Marsh Award.

problems, theorem proving, algorithms for quantification theory.

3. Procedures for search and learning, search in discontinuous and discrete systems, random versus systematic methods, convergence and random walk. Pandemonium and Perceptrons.
4. Abstract algebra and linear graphs, applications of lattice theory, semigroups, rings, and so on, to coding languages, and sequential transducers; application of linear graphs to route problems, state diagrams, etc.
5. Synthesis procedures, design with "neurons" or other specific types of element, reliability.

Correspondence to Symposium Committee, Polytechnic Institute of Brooklyn, 55 Johnson Street, Brooklyn 1, N.Y.

Supplement to the Oxford English Dictionary

The following is the sixteenth list of aeronautical terms for the Supplement to the Oxford English Dictionary for which assistance in tracing earlier references is required. If members know of an earlier use than that given for any word in the following list they are asked to write to the Editor, Oxford English Dictionary Supplement, 40 Walton Crescent, Oxford, giving the reference(s), date, author, title, chapter and page. Thanks are expressed to those who have already responded to previous appeals.

lofting (Aircraft Engineering)	1939	*Journal of the Royal Aeronautical Society*
loftsman (as above)	1947	*Aircraft Engineering*
log-book (of an aircraft)	1917	C. Grahame-White, *Air Power*
low-wing, attrib.	1929	N.A.C.A. *Technical Memorandum No.* 517
manned (Aeronautics, as bomber)	1906	*Nature*, 8th November
marker (flare, etc., used in air-bombing)	1944	*The Times*, 22nd March
marker beacon	1929	*Technical News Bulletin*, Bureau of Standards, Nov.
marker bomb	1944	Hutchinson's *Picture History of the War*
Met. (abbr. of Meteorological)	1940	*War Illustrated*, 26th January
mid-wing monoplane	1934	*Flight*, 15th February
mine-layer (aircraft)	1939	*War Illustrated*, 16th Dec.
mine-laying (by aircraft)	1939	*War Weekly*, 8th December
missile (=guided missile)	1945	*Scientific American*, Nov.
missile base	1956	W. A. Heflin, *U.S. Air Force Dictionary*
missile-firing	1958	*The Listener*, 20th February
mission (operational sortie)	1939	*Aircraft Year Book*

News of Members

R. P. Dickinson (*Fellow*) formerly Superintendent of Performance A. & A.E.E., is now Superintendent of Weapon Systems Division.

Sqn. Ldr. J. R. E. Fullerton (*Associate Fellow*) formerly Group Radio Officer, H.Q. No. 3 Group, has retired from the R.A.F. and is now a Senior Technical Officer, Department of Supply, Woomera, S. Australia.

A. H. C. Greenwood (*Associate Fellow*) in addition to his new appointment as Manager, Aircraft Sales and Service, British Aircraft Corporation, retains his position

on the Vickers-Armstrongs (Aircraft) Ltd. Board as Sales Director. (Correction to November JOURNAL.)

C. E. HARRISON (*Associate Fellow*) formerly Chief Test Engineer, Rolls-Royce of Australia, Mascot, is now Manager, Bendix-Tecnico Pty Ltd., Rockdale, N.S.W.

C. KELL (*Associate Fellow*) formerly of the Aerodynamics Dept. at R.A.E., Farnborough, is now Chief Experimental Officer at R.A.E., Aberporth.

ELECTIONS

The following is a list of elections and transfers of membership of the Society:—

Associate Fellows

Joseph Cecil Ainsworth
John Marles Herbert Barnard (*from Graduate*)
William Ralph Bishop Bryder (*from Student*)
Brian Stevens Campion (*ex-Student*)
Leslie George Carpenter (*from Associate*)
Roger Sidney Dabbs (*from Graduate*)
Mary Donne Ellis
Lawrence Frank Gillard (*from Graduate*)
Vincent Girvin (*from Student*)
Dennis Gerald Cave Goodhead (*from Graduate*)
John Moss Hearsey (*from Graduate*)
William Alexander Hodgson
John Watkins Jones
John Llewellyn Joyce
Edward Large
Ronald Arnold Frank Lee
Frank Gibson Lester
Thomas Edwin Loadwick
Michael Christopher McGovern
David Parkinson Miller (*from Graduate*)
Ian Stanley Milligan
Terence Pugh O'Brien (*from Graduate*)
Kenneth Pidd
Robert Bernard Rypinski
David William Scott (*from Associate*)
Anthony Cecil Seaford
William Douglas Simpson
Alfred David Nesbit Smith
John Walker (*from Graduate*)
Norman James Wilson (*from Graduate*)
Michael Leyland Woodward (*from Graduate*)
Ivan Ray Yates (*from Graduate*)

Associates

Peter John Clay
Arthur William Cole
John Anthony Hallam
Kenneth Ernest Toop

Graduates

Brian William Aldridge
Samuel Colin Bendall (*from Student*)
William Frederick Bennett (*from Student*)
Gawain Hugh David Bradburn (*from Student*)
Robert Keith Burton (*from Student*)
Frederick Cattell
Choon Chandrsuda (*from Student*)
Ivor Corkell (*from Student*)
Alan Joseph Dodd
Ian Frank Fairhead
Christopher Robin Gilding
Barrie Donaldson Gray
George Hayhurst
Darryl Garth Jeune
Graham Stanley Jost
David Edward Langford (*from Student*)
David Walter Le Masurier
Brian Lowe (*from Student*)
Graham Houston Macdonald (*from Student*)
John Charles McHarrie
Jeffrey Arthur Morgan
Gerald Michael Moss (*from Student*)
Colin Orpe (*from Student*)
Robert Glassford Paterson (*from Student*)
Roger Charles Jacklin Phipps
Peter Rex Schofield (*from Student*)
George Edward H. Vane-Stewart
Brian Warburton
Douglas Wright
Peter John Yorke (*from Student*)

Students

David Roger Allen
Jaswant Singh Bhatti
Philip Douglas Cass
Geoffrey Kenneth Clarke
Bernard Harold Featherstone
William Alfred Hawkins
Ronald George Knight
Andrew Duncan McLaren
Grahame Duncan Miller
Robert Michael Palmer
Colin Reginald Shurmer
William Alan Frederick Tunbridge
Brian George Wilson

Companions

Gordon Rodney Chamberlain
Donald Chambers
Elizabeth Barbara Croad
Edward John Mastronardi
Walter John Scott
Douglas Robert Wilkie

Lecture Summaries

THE AIRLINES APPROACH TO AIRCRAFT SELECTION

R. NIVET

Main Society Lecture to be given at the Manchester Branch on 13th December

The air liner must be well adapted to its purpose, correctly maintained and efficiently used; but above all, it must be unsurpassed by a better one which could do the job better. Correct aircraft selection is, for an airline, the key to economic success.

This results from two characteristics of air transport: fierce, but regulated competition which, at least on international routes, cannot use fare differentials, but only quality of service to attract passengers, and also the critical aspect of air transport economics, with ever increasing costs, reduced profit margins, and tremendous capital needs.

The selection of aircraft by an airline is based on assumptions made on future traffic. Such assumptions are generally based on the use of traffic surveys and forecasts. Great care must be exercised in the process of forecasting traffic trends, mostly when new classes of traffic such as cargo, shorthaul or very low fare traffics are concerned.

One of the first steps in aircraft selection is necessarily a forward planning of schedules; this is because the choice of itineraries, flight frequencies, schedules, have a definite bearing on traffic, and the economics of the system. Fleet size and general characteristics of the aircraft needed are derived from this forward planning. The important point in the process is to cross-check constantly decisions and assumptions. Relating traffic forecasts and procurement needs is a managerial function as it implies the definition of policies in such fields as operation of critical sectors, adaption of capacity to demand in off-peak and peak traffic periods, disposal or re-use of equipment.

A technical and economic evaluation of particular aircraft permits the selection of the type most adapted to the airline needs. Great care has to be exercised in the economic appraisal when operation of new types is concerned, for which accurate cost figures are not easily established, and in the assessment of all the implications of introducing a new aircraft type.

Because of the many implications outside the technical field, the approach to aircraft selection must be global: it is a synthesis of all airline activities and implies a continuous planning process. Because of its vital consequences, aircraft selection is, for an airline, a major managerial activity. It implies judgment, foresight, and co-operation at a very early stage of design, with manufacturers and regulatory bodies.

Rotorcraft Section

ROTATING AEROFOILS AND FLAPS

DR. S. NEUMARK

To be given on 5th January 1962

The introductory part deals with the aerodynamic properties of auto-rotating and forcibly rotated aerofoils. The main problem of lift, drag and torque presents very serious difficulties, since no theoretical solution exists, and what is known is based on some scanty experimental evidence. The latest war-time German results (unpublished) are summarised and illustrated by graphs. A rotating aerofoil may produce a very large lift (C_L reaching 12 or possibly more) accompanied, however, by a very large drag. C_L depends primarily on the ratio u/V of peripheral to mainstream velocity, and reaches its maximum at a certain optimum value of u/V. The ratio C_L/C_D remains small, but the ratio of $C_{L,\max}$ to $C_{D,\min}$ (the latter for $u=0$) can reach enormous values, impossible to achieve by any other lifting device. The lift is associated with circulation, and there is some analogy with Magnus effect for rotating circular cylinders; the influence of aspect ratio and endplates is also similar.

The main part deals with a small rotating aerofoil (flap) attached to an ordinary large aerofoil. The rotating flap, if conveniently located (just below the T.E. of the mainplane) can act as a powerful lift-augmenting device. It can also be used, in various positions, as a control element, namely force and/or torque motivator. The complicated and interesting properties of the system may be studied theoretically for the two-dimensional case, following the principles of classical aerofoil theory, treating the flap simply as a vortex generator, and applying the Kutta-Joukowski condition. Results of a recent investigation on these lines are presented, firstly as regards the considerable "induced" lift acting on the mainplane (in addition to the ordinary Magnus lift $\rho V\Gamma$ on the flap). The "lift magnification factor," pressure distribution, streamline patterns, and internal aerodynamic forces between mainplane and flap, are discussed and illustrated by graphs. Some war-time German experimental results are described, and the possibilities of further progress considered.

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 65 DECEMBER 1961 NUMBER 612

49th Wilbur Wright Memorial Lecture

Researches in Space Flight Technology

Dr. ABE SILVERSTEIN, B.S., F.R.Ae.S., F.I.A.S.

(*Director of Space Flight Programs, National Aeronautics and Space Administration*)

The Forty-Ninth Wilbur Wright Memorial Lecture, "Researches in Space Flight Technology," was given by Dr. Abe Silverstein, B.S., F.R.Ae.S., F.I.A.S., Director of Space Flight Programs, N.A.S.A., before a large and distinguished audience in the Lecture Theatre, 4 Hamilton Place, on 12th September 1961. Air Marshal Sir Owen Jones, K.B.E., C.B., A.F.C., B.A., D.I.C., F.R.Ae.S., M.I.Mech.E., R.A.F.(retd.), President of the Society, presided. The Lecture was given during the Eighth Anglo-American Aeronautical Conference, and the President was accompanied on the platform by Dr. H. Guyford Stever, President of the Institute of the Aerospace Sciences, and Head of the Mechanical Engineering Department at the Massachusetts Institute of Technology, and Air Commodore W. P. Gouin, R.C.A.F., a member of the Directing Staff of the National Defence College, Canada, and President of the Canadian Aeronautical Institute.

As has become the custom, before the Lecture was delivered, the President presented the awards made by the Council for 1961 for outstanding contributions to aeronautics. The list of awards presented on this occasion was published in the June 1961 JOURNAL (p. XXVII).

Introducing the Lecturer, the President reminded the audience that the first Wilbur Wright Memorial Lecture was given in 1913 by Horace Darwin. The list of Lecturers, as they would see in their programmes, contained the names of eminent scientists and engineers from America and from this country. They had with them on this occasion a number of those who had given the lecture, among them their very distinguished visitor, Dr. von Kármán.

This lecture had been given alternately by a lecturer from this country and one from the United States, with one exception. On one occasion it had been given by the late Professor Ludwig Prandtl—a name well-known to them all.

Now Dr. Abe Silverstein was to give the 49th Wilbur Wright Memorial Lecture and had chosen as his subject "Researches in Space Flight Technology." Dr. Silverstein was Director of Space Flight Programs at the National Aeronautics and Space Administration headquarters in Washington. Before the N.A.S.A. was established on 1st October 1958, Dr. Silverstein had been Associate Director of the Lewis Flight Propulsion Laboratory, Cleveland, a research centre of the National Advisory Committee for Aeronautics, which formed a nucleus of the N.A.S.A. Dr. Silverstein joined the N.A.C.A. in 1929 and spent much time at the Langley Aeronautical Laboratory on wind tunnel design and high speed research until he was transferred to the Lewis Laboratory in 1943 to direct research at the Altitude Wind Tunnel. He had done pioneering work on large scale ram-jet engines and on the supersonic wind tunnels at Lewis.

1. Introduction

It is a great pleasure and an honour to be with you today as we again pay tribute to the great pioneer of manned flight, Wilbur Wright. We may all be proud of the marvellously intricate, yet broad base of science and technology that has been created in the 58 years since his first flight. The aeroplane has revolutionised Man's way of life on earth, and the early dreamers who aspired towards flight as a new adventure dreamed better than they could have known. The search has ever been towards achieving higher flight speeds, higher altitudes, and longer ranges. The jet transport, the supersonic aircraft, the X-1 through to the X-15 research aircraft, and the ballistic missiles are generic developments from this common philosophy and they are rooted in, and supported by, the same basic sciences and applied technology. In the same way the technology of manned space flight which this year achieved its first successes was built on the same foundation.

The rapid progress attending the first few development years of manned and unmanned exploration of space attest to the firmness of the footing. However, with a vision of manned exploration of the universe and a searching out of its secrets by visits to the moon, the planets, and beyond, how do we evaluate the adequacy of what we now know? What are the researches that will enable the vision to be translated

Dr. Silverstein.

into the hardware of space vehicles and into the reality of space operations?

It is towards what obviously must be an incomplete answer to these questions that the lecture will be directed.

Even a cursory examination reveals how little is known to accomplish the ambitious missions of the future. This same quick look, however, fails to reveal problems that are not answerable to the research techniques developed in the years since Wilbur Wright flew at Kitty Hawk.

It is with the combination of vision and superb research techniques that the missions will surely be accomplished, unless continuing studies reveal as yet unrecognised problems that require a breakthrough in the science.

Refinement of research techniques and of the applied technology is an overwhelming requirement for space flight. Through the years the performance premium for weight saving in aircraft and missiles demanded the most refined techniques of all the engineering fields. To compensate for a pound of excess weight in a subsonic jet transport requires of the order of a pound of additional take-off thrust. In a direct-ascent lunar landing mission a badly engineered pound in the re-entry capsule may require an additional 1,000 lb. of initial boost thrust to compensate. The driving urge then is towards acquiring more accurate research data and refined methods of analysis so that the basic design can be created with minimum margins allowed for flight safety.

It is in the use of full-scale flight testing for establishing design criteria and acquiring accurate research data that space flight is most severely limited. The carefully instrumented aircraft that can be flown cautiously to reveal its design flaws, returned to base for rework, and reflown again and again, provides an economy in both effort and money that is not yet available to the space flight designer.

Until techniques for return of test space vehicles and spacecraft are developed, the temptations to reduce margins for safety and thereby reduce the thrust requirements must be judiciously tempered, since it is from the safe accomplishment of a mission that the most new data can now be acquired. Heavy emphasis on ground-based research and on satellite and space probe flights for engineering tests will need to be continued for the next few years to provide the bulk of the design information.

In the following sections brief discussions will be given of some current researches using these techniques that are aimed towards advancing space flight mission capabilities. References in general will be to work of the National Aeronautics and Space Administration, since information on current researches in N.A.S.A. was most readily available to the author. Broad areas of interest will not be mentioned. Problems in the areas of propulsion, aerodynamics, and structures are presented without extensive technical detail. The intent is to arouse interest in the problems and perhaps invoke the participation of others in helping to solve them.

2. Propulsion

The burden of providing increased space flight capability for the future, as it has in aircraft development, falls most heavily on the shoulders of those responsible for the development of the propulsion and associated launch vehicle systems. The higher the total velocity to be imparted to the spacecraft, the greater

FIGURE 1 (*left*). 15,000-pound thrust liquid hydrogen engine.

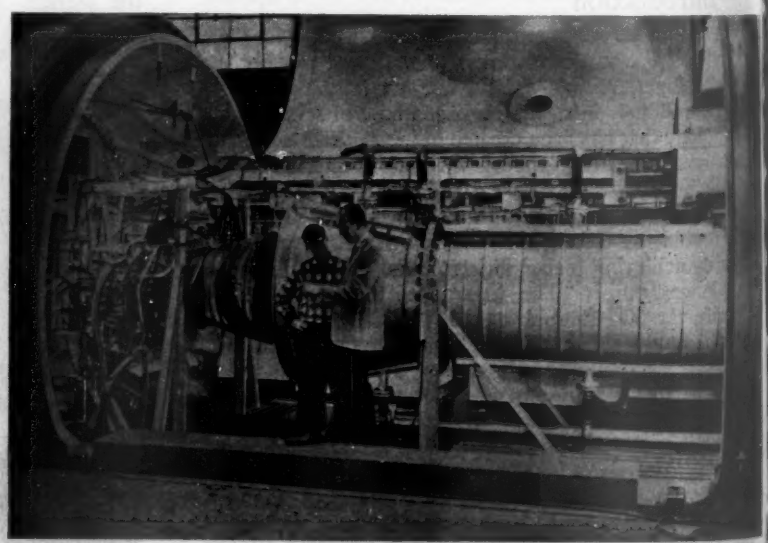


FIGURE 2 (*above*). Liquid hydrogen engine and altitude tank.

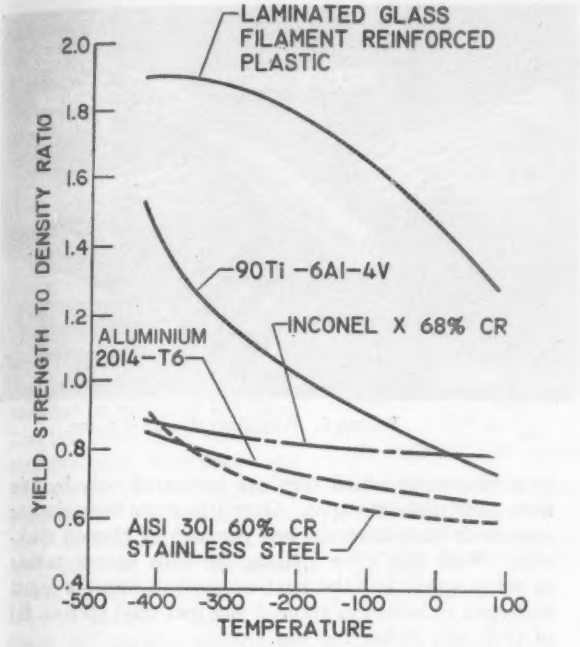


FIGURE 3. Material strength-to-density ratio as a function of temperature.

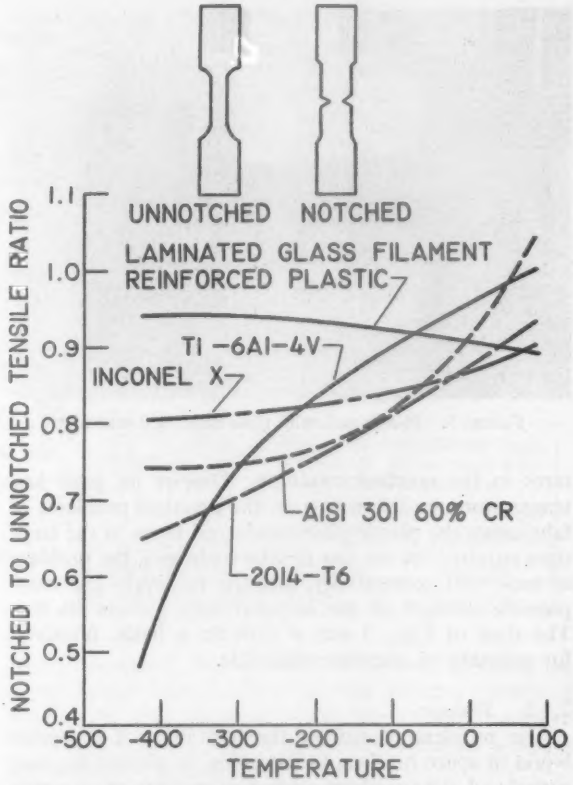


FIGURE 4. Notch sensitivity of various materials as a function of temperature.

is the premium on high propulsive performance. In the lunar landing and return mission in which a total velocity of about 56,000 feet per second is required, a multi-stage, all-solid-fuelled rocket vehicle may require as much as 40 million pounds of thrust in the first-stage rocket, and the launch vehicles may weigh 25 million pounds. In contrast, a three-stage launch vehicle with liquid propellant first and second stages, and a nuclear heat exchange rocket as a third stage can accomplish the same mission with about 0·1 of this launch thrust and weight.

Many analyses have shown the large gains in performance possible from the use of liquid hydrogen, either in combination with liquid oxygen or fluorine in a chemical rocket, or used as the propulsion fluid in the nuclear rocket. The specific impulse of a rocket (lb. thrust/lb. fuel/sec.) which is a principal measure of rocket performance varies with $(T/m)^{\frac{1}{2}}$, where T is the absolute temperature of the gas before expansion and m is the molecular weight of the gas expelled. The low molecular weight of the propulsion gases, which are water vapour and hydrogen in the case of the LH_2/LO rocket, and H_2 for the nuclear rocket account for the high performance.

To make available this high performance with liquid hydrogen for advanced missions, N.A.S.A. has initiated development of a 15,000-pound thrust rocket engine, a 200,000-pound engine, and in a co-operative effort with the United States Atomic Energy Commission, a heat transfer nuclear rocket engine. A photograph of the 15,000-pound thrust rocket and a view of it under test in a high altitude facility at the Lewis Research Center are shown in Figs. 1 and 2.

The use of liquid hydrogen as a fuel, with its temperature of 425°F below zero, a density only 1/15 that of water and a coefficient of expansion ten times that of most liquids, introduces a host of challenging research problems associated with its tankage, insulation and storage in space, pumping, and the location of the liquid and vapour in the tank during the weightless period of flight. All of these problems are under study and a few of the results will be given.

2.1. LIQUID HYDROGEN TECHNOLOGY

2.1.1. *Tanks*

Materials for tanks storing liquid hydrogen must have a high strength-to-density ratio and be insensitive to stress concentrations due to minute notching or cracking of the material. In initial developments, stainless steel has been used to provide these properties. Unpublished results of research at the N.A.S.A. Lewis Research Center are shown in Figs. 3 and 4 for a series of metallic tank materials and for a plastic resin tank material with fibre glass filaments for reinforcement. A discussion of plastic tanks was presented to the Society recently by A. F. Newell[1], and a photograph of one used as a solid rocket case is shown in Fig. 5.

All of the tank materials showed improved tensile yield strength-to-density ratios at low temperatures for the unnotched conditions (Fig. 3) but only the plastic tank showed improved characteristics at low tempera-

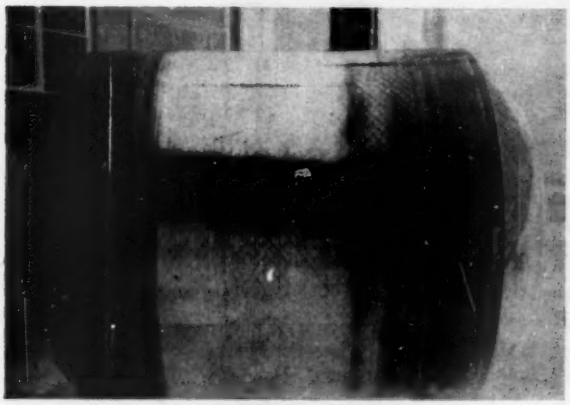


FIGURE 5. Plastic tank with glass fibre reinforcement.

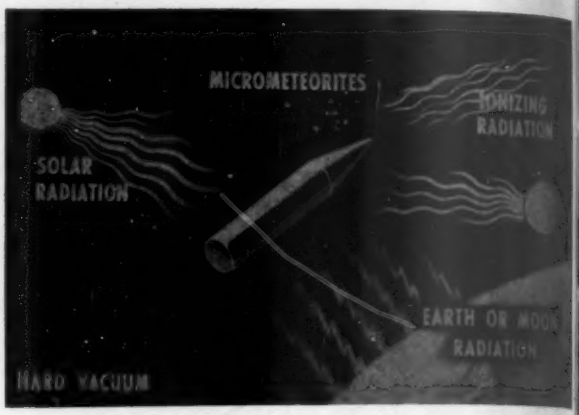


FIGURE 6. Propellant storage in space.

tures in the notched condition. Despite its good low temperature tensile properties, the practical problems of fabricating the plastic-glass reinforced tanks in the large sizes required for the low density hydrogen, the problem of tank wall permeability, and the relatively low compressive strength of the material may prevent its use. The data of Figs. 3 and 4 provide a basis, however, for selection of alternate materials.

2.1.2. *Storage*

The problem of storing the high-impulse cryogenic liquid in space or close to the moon or planets for long periods of time without undue propellant evaporation losses, and without severe weight penalties for insulation, is currently receiving heavy emphasis. Storage time will depend on the mission, being a week or weeks for lunar missions and possibly months or several years for the planetary or inter-planetary flights. Some of the environmental factors that establish design criteria for the storage, such as solar radiation, micrometeoroids, and so on, are illustrated in Fig. 6.

In a comprehensive examination of solar and planetary heatings of cryogenic propellants in space[2], and an unpublished review of the data by Dr. R. J. Brun of N.A.S.A.'s Lewis Research Center, widely spaced reflector surfaces (shadow shields) were found to be very effective in reducing propellant heating from the sun. Ten shields of the type shown in Fig. 7 were found to reduce the heat absorption rate of the hydrogen through the end of the tank from 1,000 Btu (per day) (per sq. ft.) for a bare tank to 0·1 Btu (per day) (per sq. ft.) for the shielded tank. The spacing between each shadow shield was assumed as 0·01 of the shield diameter and the absorptivity and emissivity of all surfaces was assumed to be 0·1.

As the spacing between the shields is increased more heat can be radiated to outer space from each shadow shield (Fig. 7) so that the same heat absorption of 0·1 Btu (per day) (per sq. ft.) is obtained with 30 shadow shields 0·001 diameter apart or from four shadow shields 0·1 diameter apart. Difficulties with supporting the shadow shields at a distance from the tank surfaces has led to the search for other forms of radiation protection. One method is to stack the reflecting surfaces in a blanket in which they are separated only by thin fibre glass mats or paper. Over 100 metal foils plus the separators have been stacked per inch of blanket thickness. With this close spacing the foils cannot radiate to outer space and the heat absorption into the liquid hydrogen increases to about 5 Btu (per day) (per sq. ft.) of tank end facing the sun.

This technique appears more promising than shadow shielding when the vehicle cannot be oriented to face the sun, or when it is in the vicinity of the planets and exposed to their radiation. Shield installations then become awkward since protection is required on all surfaces of the tank. The multifoil technique appears to offer considerable promise for long-term protection of hydrogen in space, but many problems yet remain to be solved. Suggestions have been made for improving the effectiveness of the multifoils by use of surface coatings with a low solar absorptivity. By a combination of properly designed radiation shields, by orientation of the vehicle so that the engine faces the sun, and by arranging the tanks properly behind the engine, calculations indicate that the hydrogen loss in space due to thermal radiation from the sun can be reduced to a value as low as 0·003 per cent per day (Fig. 8)[2].

2.1.3. *Meteoroids*

The greatest hazard for long-time storage of

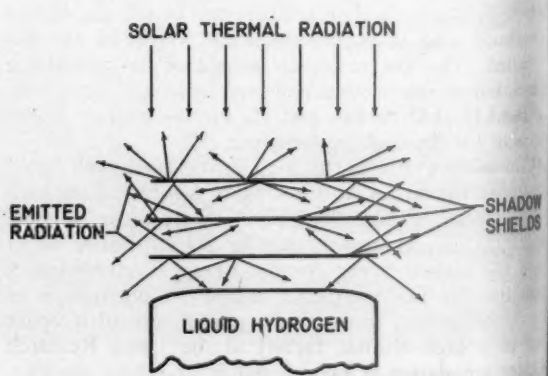
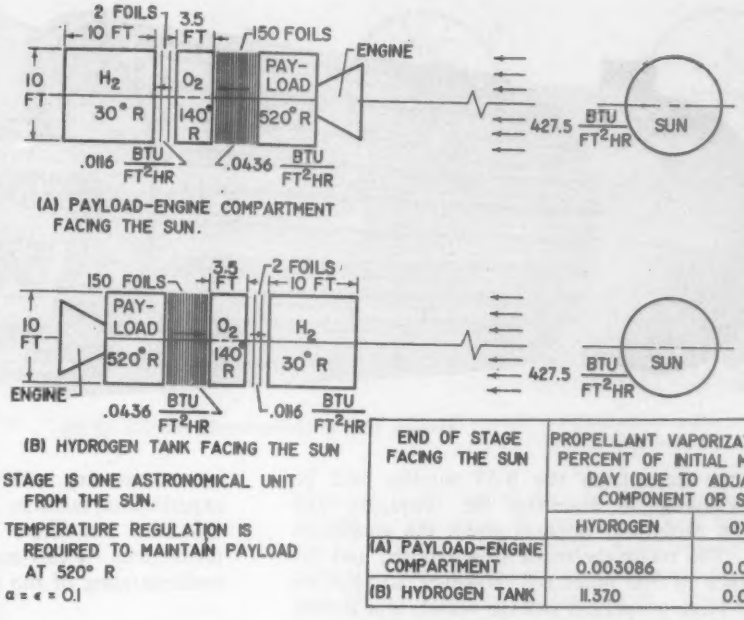


FIGURE 7. Radiation to and from shadow shields.



END OF STAGE FACING THE SUN	PROPELLANT VAPORIZATION RATE, PERCENT OF INITIAL MASS PER DAY (DUE TO ADJACENT COMPONENT OR SUN)	
	HYDROGEN	OXYGEN
(A) PAYLOAD–ENGINE COMPARTMENT	0.003086	0.002334
(B) HYDROGEN TANK	11.370	0.002334

FIGURE 8. Effect of stage orientation with respect to the sum of propellant vaporisation rates.

propellants in space is tank puncture from meteoroids. Information is scarce on the density, composition, velocity, size, and direction of the meteoroids, as well as on the type of damage incurred by the materials that are impacted. Both problems are under study and microphones have been installed on many of the satellites that have been orbited to measure the frequency and momentum of the impacting meteoroids. A recent summary of the data by C. W. McCraken, *et al*[3] including results from Explorer VIII (Fig. 9) shows a lower incidence of heavier meteoroids and consequently a lower hazard to space vehicles than had previously been predicted from extrapolated data on the curve marked "Whipple."

The experimental programme on meteoroid impact is being extended by flights with the S-55 satellite (Fig. 10) launched by the Scout vehicle. The satellite is 24 in. in diameter and 76 in. in length and surrounds the fourth stage of the Scout vehicle. Five different types of sensing elements are incorporated into this satellite as follows: —

(1) Pressurised beryllium-copper capsules. A meteoroid puncture of a capsule will be detected by a pressure-sensitive microswitch located in each capsule. There are 160 capsules of four different wall thicknesses: 1·0, 1·5, 2·0 and 2·5 mils.

(2) Foil gauges. Each sensor consists of a very fine printed electrical circuit bonded to a ¼-mil sheet of Mylar, which is in turn bonded to the back of stainless-steel sheets 9 sq. in. in size. A meteoroid puncture of a stainless-steel sheet is detected by the break in the printed electrical circuit.

(3) Wire grids. Wire-wound cards will expose a total area of about 2 sq. ft. As with the foil gauges, a meteoroid impact on each card is expected to open the electrical circuit of that card.

(4) Cadmium-sulfide cells. The sensors consist of mirrored hemispheres with a Cd-S crystal (sensitive to light) located at each focal point. Over the mouth of the hemisphere is stretched a Mylar sheet coated with vapour-deposited aluminium. Puncture or erosion of this coating by micrometeoroids allows sunlight to enter the cell and to be sensed by the Cd-S cell.

(5) Piezoelectric impact detectors. Piezoelectric crystal impact-detecting transducers are mounted at various positions on the satellite. These detectors note meteoroid impacts made on the metal surface on which each is mounted. For example, a detector mounted on a pressurised capsule (item (1)) will detect a meteoroid impact on that capsule, while the pressure-sensitive microswitch inside the capsule will determine whether the capsule is punctured.

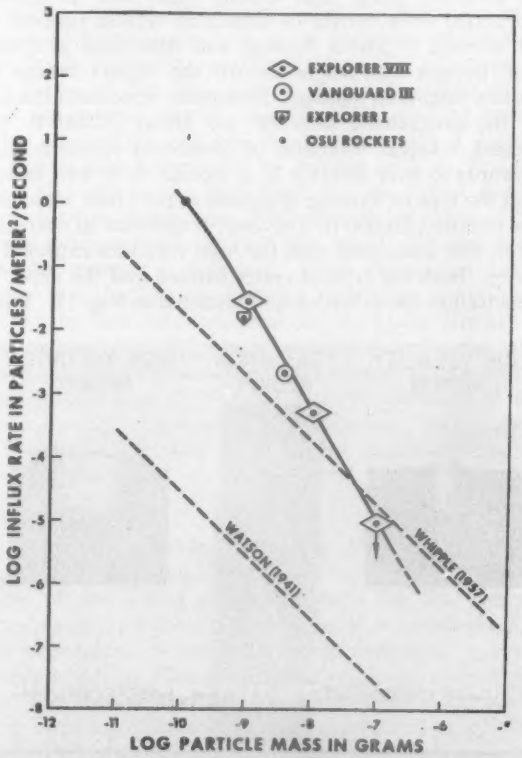


FIGURE 9. Meteoroid measurements from satellites and sounding rockets.

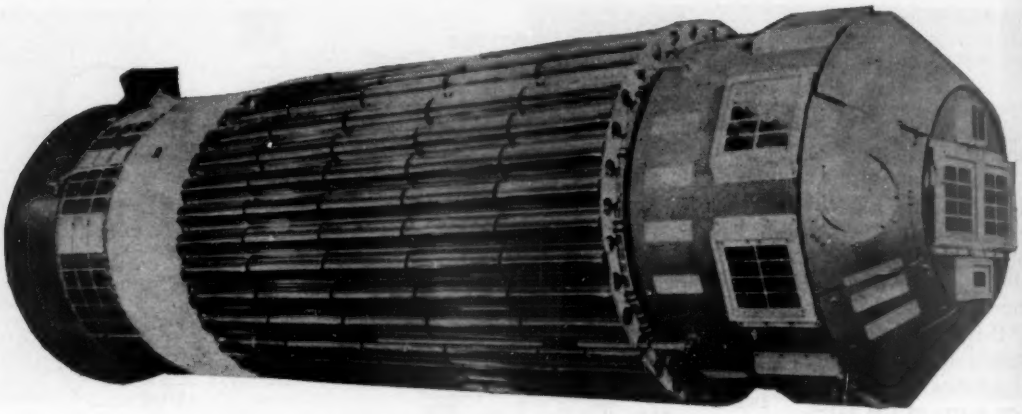


FIGURE 10. Micrometeoroid satellite (S-55).

All of the data from the S-55 satellite will be extremely valuable in assessing the frequency and damage from meteoroid impacts under the conditions of the test. The relatively small area exposed and the orbital altitude of 300 miles fail, however, to simulate the flight of large propellant storage vessels into distant space. For a determination of the damage associated with meteoroid impact and methods of protection, it is believed that the damaged space vehicles must be recovered and examined on the ground. Experiments to obtain these results are now being planned.

In lieu of these data, ground-based experiments are in progress using high-velocity guns and projectiles impacting on a variety of simulated vehicle surfaces in an attempt to assess damage and determine preferred skin designs that might absorb the impact energy or sustain minimum damage. Maximum velocities achieved in the programme thus far are about 30,000 ft. per second, whereas estimates of meteoroid velocities vary upwards to over 200,000 ft. a second. It is well known that the type of damage sustained at the lower velocities, for instance, 20,000 ft. a second, is different in character from that associated with the high velocities expected in space. Both the type of crater formed and the depth of penetration are different, as illustrated in Fig. 11. There is a continuing effort to develop new ground-based experimental facilities for accelerating particles to higher velocities and there is hope that simulation of the phenomena by this equipment will greatly expedite our understanding of the subject.

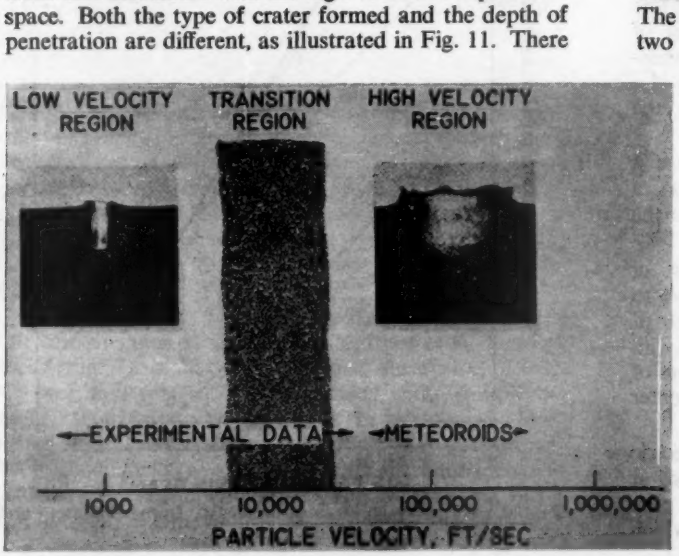


FIGURE 11. Meteoroid impact phenomena.

2.1.4. *Weightless flight*

Tank venting, pressurisation, and engine re-starting during coasts in orbit or flight through space introduce the question regarding the location of the propellant and propellant vapours during this weightless period of flight. The normal hydrostatic and convective forces are absent and surface tension forces prevail. Since conventional methods that have been suggested for attacking this problem, such as the use of bladders and acceleration rockets, fail to take care of all contingencies, such as venting in long coast periods, the N.A.S.A. Lewis Research Center has initiated an interesting research approach in which the fluid surface-tension forces are used to position the liquid mass during the weightless period.

Some experiments which show this effect have been conducted in a drop tower at the Lewis Research Center. The test container was a glass sphere approximately two and a half inches in diameter partially filled with ethyl alcohol which readily spreads upon glass. Fig. 12 shows the sphere at a filling of 40 per cent first in a one-*g* field and then in a zero-gravity field.

During the near weightless condition simulated by the drop, the liquid vapour interface will establish a spherical shape which has the minimum surface energy. The tendency of the liquid-vapour surface to form a sphere is clearly seen. Unfortunately this sphere has no preferred location and could easily come to rest over the pump inlet. If, however, a structure is erected from the bottom of the tank such that the vapour bubble cannot find enough clear space for a spherical shape to form, it should

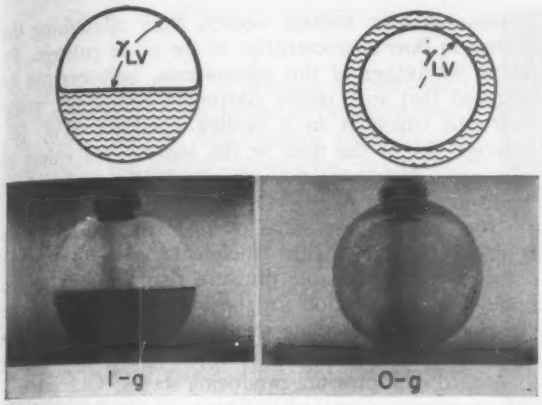


FIGURE 12. Liquid vapour distribution in a sphere—40 per cent filled.

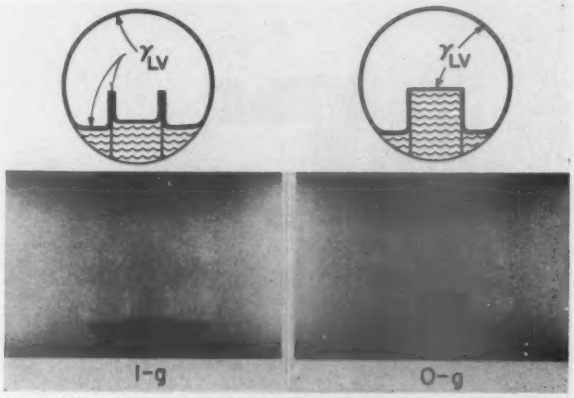


FIGURE 13. Liquid vapour distribution in a sphere with standpipe—10 per cent filled.

tend towards the least surface area shape imposed by the configuration of the structure.

The concept of being able to position the liquid and vapour in a propellant tank through utilisation of the principle of "minimum surface energy" has been verified in experiments in the drop tower. The two and a half inch diameter sphere used in the previous experiment was altered by erecting from the bottom of the tank a hollow cylinder with four one quarter-inch holes near its base. The top of the tube was at an elevation corresponding to the 40 per cent volume point of the sphere and the tube diameter was equal to one third the chord of the sphere at that point. With this or any smaller tube diameter a reduction in surface area is obtained if the liquid rises in the tube for all sphere fillings 10 per cent or greater. When the system is placed in a zero gravity field, liquid should rise in the tube, thus lowering the area of the liquid-vapour surface and the total energy of the system. The result of the experiments for a 10 per cent filling is shown in Fig. 13. The fluid does assume a configuration corresponding to its minimum surface area which is a condition of minimum energy. The motion pictures taken during these experiments show that the transition from the one-*g* configuration to the minimum energy configuration is smooth and definite.

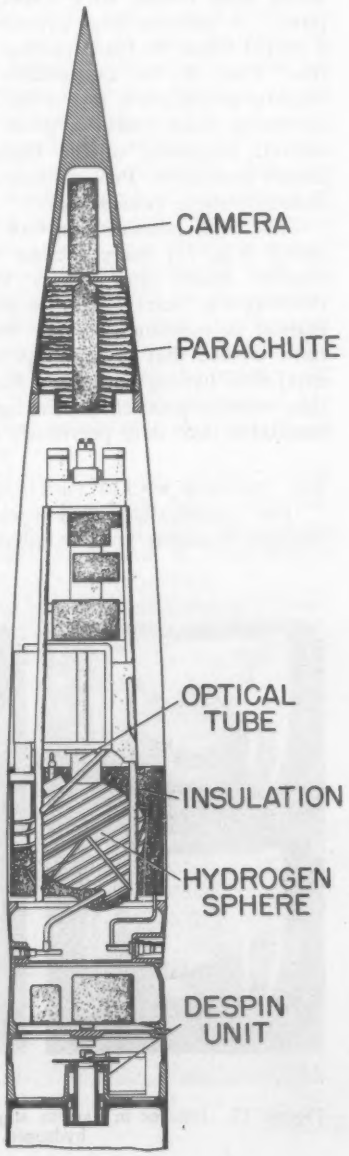


FIGURE 14. Diagram of zero-gravity experiment in nose cone of Aerobee sounding rocket.

Other experiments to investigate weightlessness with liquid hydrogen in the tank are in progress. Aeroplanes are flown along zero-*g* trajectories while photographs are taken of the fluid motion in the hydrogen tanks that are carried aboard. An Aerobee sounding rocket nose cone (Fig. 14) has been fitted with a liquid-hydrogen tank surrounded by heating coils so that the heat flux across the tank wall can be varied during periods of weightlessness. Photographs are taken of the liquid configuration, the heat flux across the tank wall, and the pressure in the tank. From the several flights made thus far, results indicate that large heat fluxes across the tank wall can break up the liquid film at the wall surface and the equilibrium pressure in the tank corresponds to the pressure at the hottest section of the tank, rather than that of the bulk temperature of the liquid. The programme is continuing and should provide valuable data in this most important area of investigation.

2.1.5. *Pumping*

Of greatest importance to the development of the liquid hydrogen rocket engine systems is the establishment of the sound design methods for the pumps. Considerable progress has been made in understanding the phenomena of pumping liquid hydrogen and the problem can be illustrated by referring to tests at the N.A.S.A. Lewis Research Center on a research model of a three-stage axial-flow pump shown in Fig. 15. The multi-stage axial flow pump shown embodies concepts developed for turbojet engines, yet it is a relatively new approach to liquid pump design. The three typical

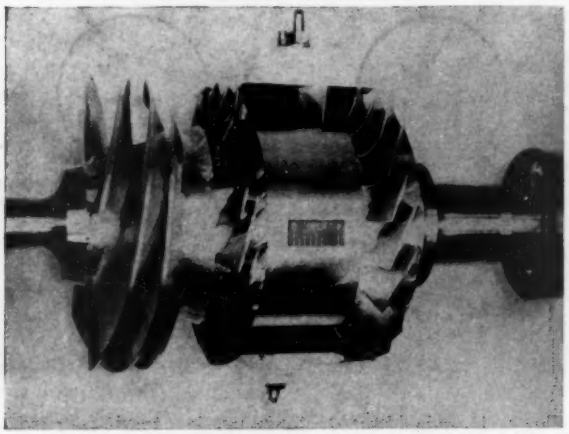


FIGURE 15. Three-stage axial flow hydrogen pump rotor.

stages are the inducer, an intermediate stage, and a high-pressure stage. The inducer is the first stage and is designed particularly to minimise the adverse effects of cavitation with enough pressure rise to recondense any vapours formed and prepare the fluid for the succeeding stages.

The sensitivity of pump performance to cavitation is a function of the properties of the fluid. These include latent heat of vaporisation, specific heat, ratio of liquid to vapour density, and the rate of change of vapour pressure with temperature. Of these the most important is the liquid-to-vapour density ratio. For example, when water cavitates, the volume of vapour created is 1,600 times the volume of vaporised liquids. This vapour completely changes the character of the flow in the inducer passages and performance falls drastically. In oxygen, the density ratio is 257 : 1 and cavitation performance is better than for water. In hydrogen at its normal boiling point of 37° Rankine, the ratio is only 52 : 1. At higher temperatures, the density ratio of hydrogen is still further reduced, explaining the "temperature" effect often noted in tests. This, then, is one of the reasons that pumps have been found to have good cavitation performance in hydrogen.

When hydrogen flashes to vapour a relatively small

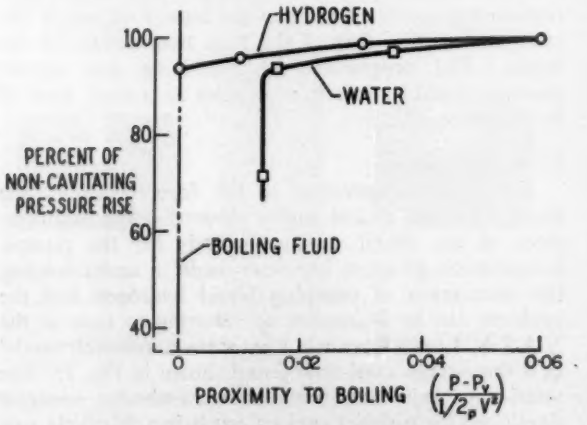


FIGURE 16. Hydrogen pump performance.

increase in flow volume occurs, thus minimising the change in flow characteristics in the blade passage. By taking advantage of this phenomena, inducers can be designed that will, under controlled conditions, pump hydrogen which is in a boiling condition (Fig. 16). Photographs of the flow at the inducer for values of inlet pressure varying down to the boiling point of the liquid are shown in Fig. 17.

The intermediate stage of the axial pump shown (Fig. 15) operates with "incipient" cavitation yet it develops an appreciable pressure rise and sets up the liquid flow distribution for the following high pressure stages. This intermediate stage may encounter an interaction between cavitation and flow instability that is associated with pressure producing stages. One interesting phenomena observed is rotating cavitation, which is similar to rotating stall in compressors; a zone of cavitating fluid rotates with respect to the blades of the pump. A periodic large cavitation zone is followed by a period when the blade passages are almost cavitation-free. One of the undesirable consequences of this rotating cavitation is that if the frequency at which the cavitating zone strikes a given blade is tuned to the natural frequency of the blade, a destructive blade failure can occur. Proper blade design can eliminate or minimise these possibilities.

The high pressure stage of the research hydrogen pump (Fig. 15) bears a close resemblance to a compressor blade row. The compressor technology developed in years of turbine engine research has been fruitful in tackling this new technology. Experiments have verified that basic compressor theory is valid for axial flow hydrogen pumps. Results up to the present time indicate good efficiencies and higher head rises are attainable than were previously thought possible.

2.2. NUCLEAR ROCKET PROPULSION

For chemically-fuelled rocket engines where the energies available from combustion are controlled by

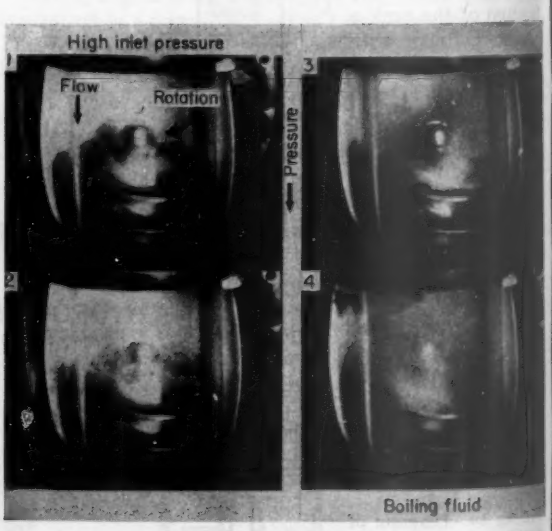
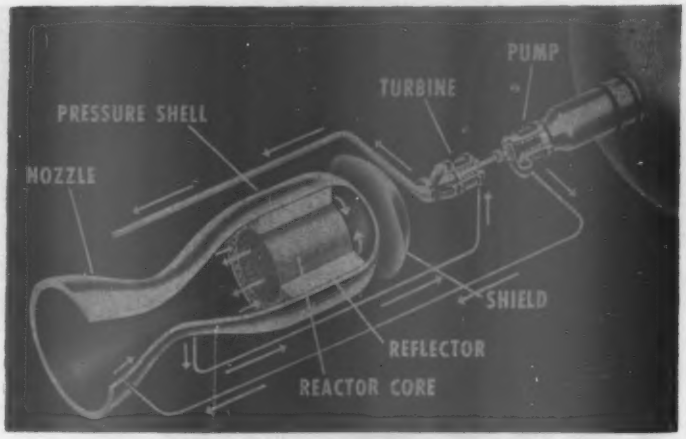


FIGURE 17. Inducer in various stages of cavitation in liquid hydrogen.

FIGURE 18. Nuclear rocket engine.



the bond energies, it is possible to compute accurately the maximum specific impulses possible from various fuel-oxidant combustion. From these theoretical calculations, it can be shown that the specific impulse (lb. thrust/lb. fuel/sec.) practicable from the most energetic chemical combinations is less than 500. The nuclear rocket offers the possibility of values of specific impulse of over 1,000 and thus the interest in its development.

For review a sketch of the nuclear rocket engine system is shown (Fig. 18). Hydrogen is pumped from the propellant tank to the jet nozzle where it is used to cool the walls of the jet nozzle. The hydrogen is stored as a liquid in the propellant tank and is at a temperature of about minus 422°F. at the entrance to the double-walled jet nozzle. After cooling the jet nozzle walls, the hydrogen cools the reflector of the reactor. The reflector portion of the reactor is used to conserve the neutrons which are required to produce the fission process. The reflector, therefore, helps to reduce the size of the reactor core and the amount of uranium that is required in the reactor. The hydrogen then passes through the reactor core where it comes in contact with fuel elements that are loaded with the uranium fuel. The capture of neutrons by the uranium causes fission of the uranium nucleus, releasing the large fission heat energy. This fission heat energy is transferred to the hydrogen flowing through the reactor past the fuel element. After being heated in the reactor, the hot hydrogen gas is then accelerated through the jet nozzle producing thrust.

The development of the technology of the nuclear rocket is already under way in a joint A.E.C.-N.A.S.A. ROVER programme. As part of this programme reactors will be developed to operate at temperatures above 3,500°F with hydrogen as a propellant. Work is also in progress on the development of the other principal components of the nuclear rocket engine system, such as the pumps, nozzles, controls and shields.

A major step forward in the programme was taken when three research reactors were tested in the summer of 1959 and the summer and autumn of 1960 by the Los Alamos Scientific Laboratory. These reactors were called the KIWI-A, the KIWI-A prime, and the KIWI-A3. The first reactor tested in July 1959, the KIWI-A, used a flat plate graphite fuel element arranged as shown in Fig. 19. The fuel element plates were inserted into an unloaded graphite support structure. Each of these plates was one quarter-inch thick and was loaded with U-235. The ribs on each plate were 0·050 in. high and acted as spacers between the adjacent plates. The hydrogen gas passed through this clearance space and was heated as it flowed through the reactor. A heavy water (D_2O) island was located within the inner ring of this wheel-like support structure. The control rods required to regulate the fission rate and, therefore, the power of the reactor were located in this central heavy water island.

A photograph taken of the KIWI-A prime reactor, the second reactor, during its full power test in July 1960, is shown in Fig. 20.

The external appearance of all three of the reactors tested was essentially the same as the one shown here. The reactor core geometry was different, however, in the later tests from the one used in the KIWI-A reactor. Hydrogen gas rather than liquid hydrogen was used as the propellant in these first tests and water rather than hydrogen was used to cool the jet nozzle and the pressure shell.

The results of all of these tests were extremely encouraging in helping to evaluate the materials used, the design procedures, and in establishing confidence in

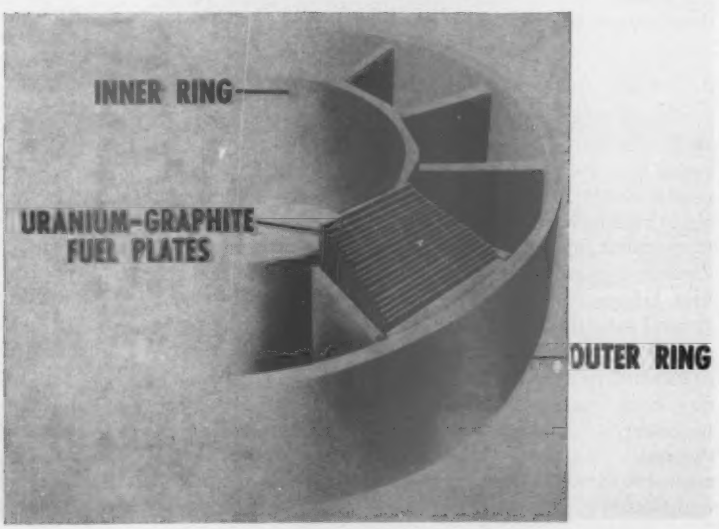


FIGURE 19. KIWI-A graphite support and fuel plates.

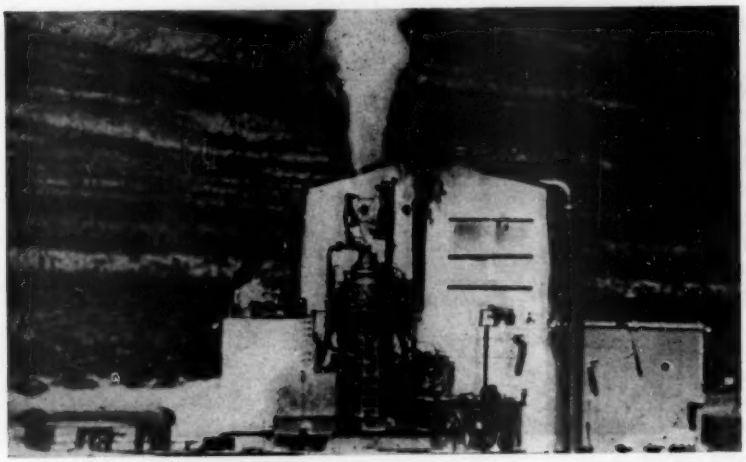


FIGURE 20. KIWI-A prime reactor.

the test conditions for the high temperature systems. A second test series will start later this year, including the use of liquid hydrogen as a propellant. The actual operation, control, and start-up of a reactor using liquid hydrogen will be regarded as a major milestone in the programme.

The creation of the nuclear rocket technology with sufficient depth to enable complete mission systems to be flown safely is one of the most difficult and challenging research areas in the current scene. The liquid hydrogen technology will need to be extended and broadened beyond the requirements of the chemical engines already discussed.

The high temperature reactor technology introduces problems of materials, heat transfer, thermal stresses, and controls in areas that have not previously been studied. The most difficult of the problems may lie in the area of system dynamics which treats with the relationships of the flow system and the reactor during transients occasioned by start-up, thrust changes, and shut-down Many of these problems are under study. The future of the nuclear rocket depends on how well the groundwork of this technology is established before development of flight hardware is attempted.

3. Aero and Aero-Thermodynamics

Space flight implies in its language operations outside the earth's atmosphere. When the N.A.S.A. organisation was chartered in October 1958 with the responsibility for conduct of civilian space activities in the United States, and the older National Advisory Committee for Aeronautics organisation was incorporated as a principal component, it was the hope that the vast complex of N.A.C.A. wind tunnels and related ground facilities for aerodynamic studies might be substantially reduced to reflect the new mission and to achieve economies in plant operation. This hope has not been realised. On the contrary, it has been necessary to construct new and more complex aerodynamic facilities to simulate flight through the atmosphere at higher speeds and higher stagnation temperatures.

In the Mercury programme, to simulate its launch and re-entry through the atmosphere from satellite speeds of about 25,000 feet per second, almost every wind tunnel in the N.A.S.A. organisation and others in the country were used to provide research data on the aero and aero-thermodynamic characteristics of the launch vehicles and spacecraft.

Some of the hydrodynamic tank facilities which had been de-activated in recent years were reopened to study the water-handling characteristics of the Mercury spacecraft and problems of astronaut escape in the water. Continuing to plague the designer are the familiar problems of loads, control, stability, boundary layers and non-steady flows, encountered, however, over a much wider range of speeds and with gas temperatures that lead in some cases to dissociation. Two of the problems of current interest that relate to re-entry from a lunar mission are outlined in the following sections.

3.1. RE-ENTRY CONFIGURATIONS

From the standpoint of aerodynamic considerations alone, a wide variety of configurations are available that will provide stable and controllable flight along a parabolic re-entry path. The criteria then for the selection of an aerodynamic shape are established by the degree of manoeuvrability required of the spacecraft along its flight path, and the requirement for minimum weight for the maximum utility.

The extent of the manoeuvrability required is determined by the accuracy of the navigation and guidance system used in the re-entry and the requirement for landing at a preselected spot. If touch-down dispersion of the order of about 1,000 miles were acceptable and if refined mid-course guidance techniques were used, manoeuvrability would not be required and a simple non-lifting ballistic-type capsule, such as used in the Mercury programme, could be used. For this case, the vehicle would have to be guided through a corridor of seven-mile width at entry if it is to enter in a single pass or avoid excessive deceleration.

To broaden the entry corridor and still achieve acceptable re-entry, aerodynamic forces must be used. If the re-entry is initiated at too high an altitude the aerodynamic force is applied in a direction to decrease the altitude, and the force is applied in the opposite direction if the re-entry altitude is too low. The corridor width for acceptable re-entry varies from seven miles for the ballistic capsule to 40 miles for a spacecraft with a lift/drag ratio of 0·5 and up to about 60 miles with a lift/drag ratio of 3·0. A scale drawing of the actual cross section of the corridor for an L/D of 0·5 is shown in Fig. 21. The small line in the centre is the corridor cross section that would have to be achieved for the non-lifting entry. With an L/D of 0·5 (Fig. 21),

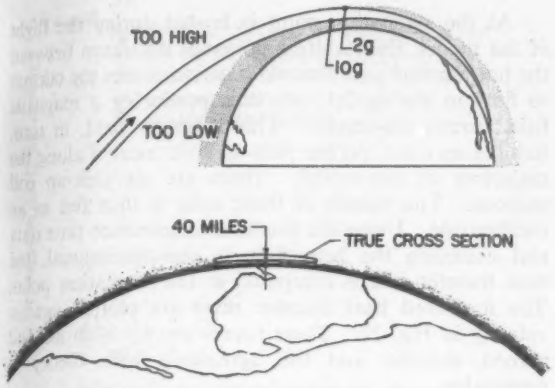


FIGURE 21. Parabolic re-entry corridor $L/D = 1/2$.

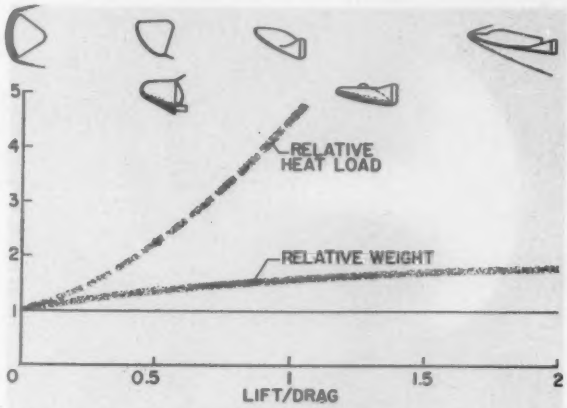


FIGURE 22. Manoeuvrability increases heating and weight.

if it were possible to position the spacecraft precisely near the upper side of the corridor, the use of lift would permit re-entry with as little as two g's maximum deceleration. The aerodynamic forces can also be used to manoeuvre the spacecraft to a preselected landing site regardless of initial navigational errors that do not exceed the allowable corridor width.

The increase in spacecraft weight and heat load with increasing values of L/D ratio (Fig. 22) emphasises the desirability of selecting design values of lift/drag as low as are acceptable to meet the manoeuvrability requirement. Studies indicate that values of L/D in the range of 0·5 to 1·0 meet these requirements for a parabolic re-entry. The configurations for this range of L/D values are generally blunt compact shapes (Fig. 22) that provide for good utilisation of their internal volume.

Extensive wind tunnel investigations at hypersonic speeds have been conducted on a variety of blunt configurations and in general it has been found possible to predict their basic force characteristics with reasonable accuracy. Moment characteristics and control force effectiveness are not predicted as reliably from the theory.

Large areas of uncertainty remain regarding the dynamic stability and control characteristics of the configurations and control surface effectiveness.

3.2. RE-ENTRY HEATING

For the past ten years the problem of heating and heat protection for re-entry from satellite speeds has been studied extensively. Adequate theoretical and experimental data have been accumulated to provide a practical heat shield design for the Mercury capsule, and full-scale flight tests have substantiated the result. For re-entry at parabolic velocity (36,000 ft./sec.) a number of additional problems must be considered.

The environment at maximum heating for the parabolic re-entry of a typical re-entry body shape described in Fig. 23 shows the extreme values of gas temperature and enthalpy encountered and the non-equilibrium state of the plasma behind the shock.

The high temperatures in the plasma behind the shock add to the usual convective heat transfer by radiation. Theoretical analysis indicates that the increased ionisation in the plasma results in higher convective heating rates. Further, the non-equilibrium state of the gases must be considered in determining the heat input.

Thus far theoretical analyses of these phenomena have not received substantial confirmation and experimental data must be obtained.

The principal experimental facilities that have been used in these studies are shock tubes and shock tunnels. A photograph of the glowing gas cap at the re-entry face of a model of the Mercury-shaped capsule tested in

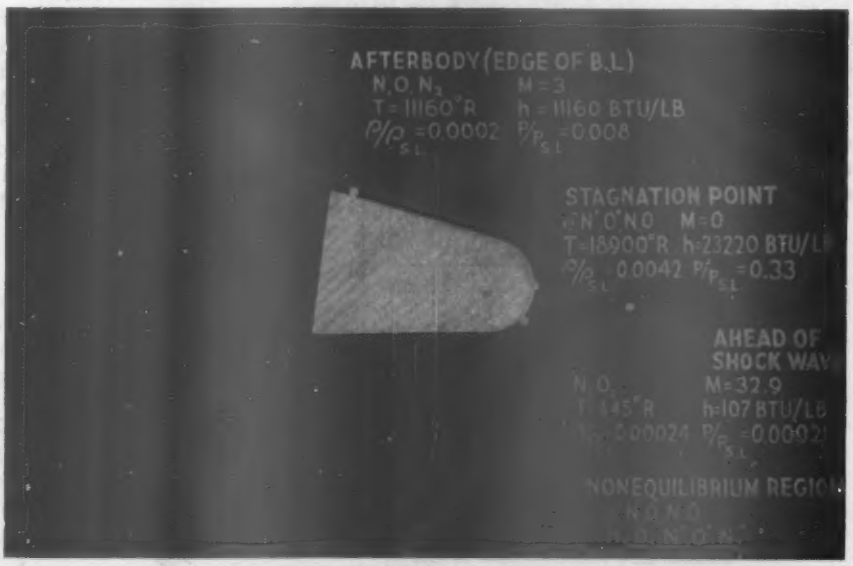


FIGURE 23. Re-entry environment.

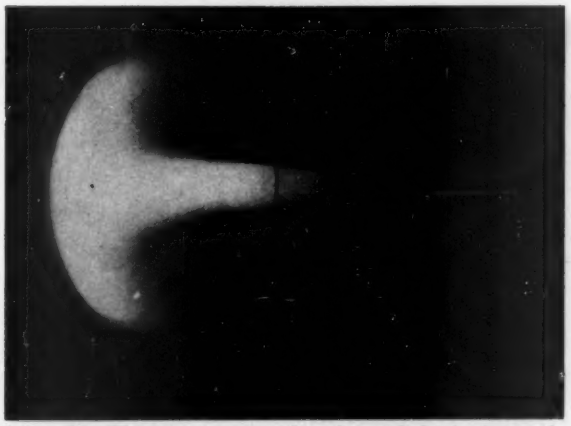


FIGURE 24. Flow over mercury-shaped capsule in shock tunnel.

a shock tunnel is shown in Fig. 24. Although these facilities provide for simulation of stagnation enthalpy, the corresponding Mach number and Reynolds number are not reproduced. Simulation of such an environment without flight tests presents a formidable problem. Nevertheless, such facilities are required and present a tremendous research area in themselves.

Recently, the N.A.S.A. Ames Research Center introduced a new technique for measuring heat transfer rates in free flight in a ballistic range which provides the possibility of correctly simulating Mach number, stagnation enthalpy and Reynolds number for some trajectories of interest.

The models launched in this ballistic range (Fig. 25) consist of a hemispherical nose with a short cylindrical section and a 120° conical tail. The model is made of aluminium and has a 0·0075-inch thick copper cap on the nose. This acts as a calorimeter heat gauge. A constantan wire is soldered to the cap of the stagnation point of the model which forms the hot junction of the copper constantan thermo-couple. A four-turn con wire on a boron nitride form is connected between the two junctions of the thermo-couple at the disc in the centre of the model and at a point on the periphery of the nose cap. To permit computation of temperature rise, the electrical resistance of the complete circuit is accurately measured before final assembly. The experimental set-up consists of a pick-up coil made of coated copper magnet wire. This entire coil is shielded in an electrostatic Faraday cage (Fig. 26).

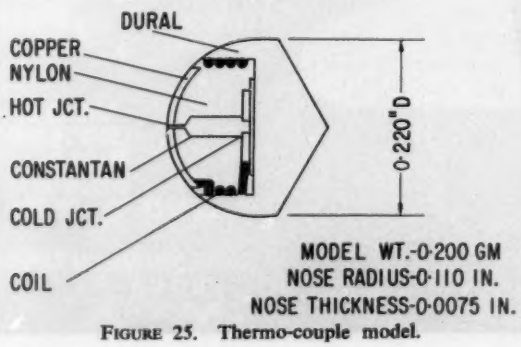


FIGURE 25. Thermo-couple model.

As the stagnation point is heated during the flight of the model, the resulting potential difference between the hot junction and the cold junction causes the current to flow in the model coil, thus producing a magnetic field around the model. This magnetic field, in turn, induces an e.m.f. on the pick-up coils located along the trajectory of the model. There are six pick-up coil stations. The output of these coils is then fed to an oscilloscope. Using the resultant temperature time data and assuming the heat flow is one-dimensional, the heat transfer rate is computed at the stagnation point. The measured heat transfer rates are plotted against velocity in Fig. 27. These results are for both air and carbon dioxide, and the agreement with theory is reasonable.

The potentiality of the system described here lies in two directions. The Mach number and Reynolds number can be varied independently and heat transfer measurements can be made near the base of the model without fear of interference of the supporting structure. This, of course, will require further development of the experimental technique.

This technique is limited to small-scale models and simulation over the afterbody and in the vicinity of control flaps will still require a large-scale flight test.

For manned re-entry at satellite or parabolic velocities with compact blunt bodies having low values of the ballistic parameter (W/C_dA), an appreciable amount of laminar flow is anticipated. This may allow the use of laminar heat transfer data obtained at lower flight speeds for locations other than the stagnation point with some degree of confidence. Heating rates in separated flows, at attachment points, and heating rates in the vicinity of protuberances are not amenable to calculation. Under some conditions heating rates as high as stagnation value have been measured on the afterbody of a typical manned ballistic re-entry capsule. When flaps are added to the configuration, the heating rates in the vicinity of these flaps can approach and even exceed stagnation values.

Considerable attention has been given to the intensity of the radiation from the equilibrium region behind a normal shock in air. The equilibrium radiation heating of the stagnation region for flight speeds up to 50,000 feet per second has been analysed using A.V.C.O. shock tube data[4] supplemented by theoretical estimates. Non-equilibrium effects at the high altitudes, however, will modify the radiation predictions estimated

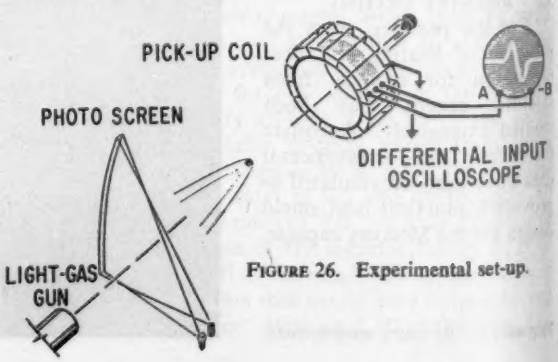


FIGURE 26. Experimental set-up.

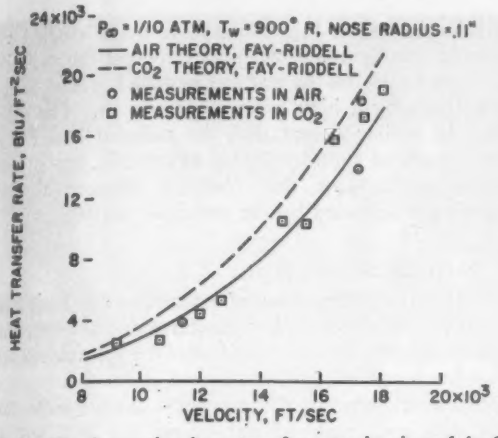

P_∞ = 1/10 ATM, T_w = 900° R, NOSE RADIUS = .11"
AIR THEORY, FAY-RIDDELL
CO_2 THEORY, FAY-RIDDELL
MEASUREMENTS IN AIR
MEASUREMENTS IN CO_2
HEAT TRANSFER RATE, BTU/FT²-SEC
VELOCITY, FT/SEC

FIGURE 27. Convective heat transfer rates in air and in CO_2.

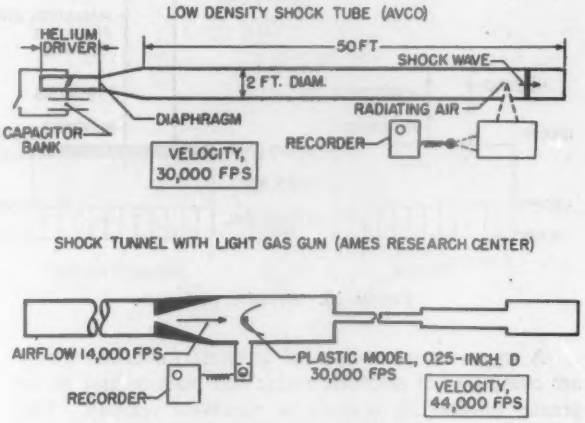


FIGURE 28. Radiation heating—ground based experiments.

using the equilibrium theory and, therefore, extensive programmes have been initiated to investigate this phenomenon. Although it is difficult to investigate plasma radiation heating characteristics in ground facilities, important progress has recently been made by the group at A.V.C.O. In an electrical shock tube (Fig. 28) a powerful electrical discharge sends the shock wave down the tube at speeds up to 30,000 feet per second. The conditions in plasma just behind the shock wave correspond to the gas cap in flight, and appropriate radiation intensity measurements can be made. It is hoped ultimately to achieve shock speeds as high as 40,000 feet per second by this technique.

The gun-fired model technique has been successfully developed and explored by the N.A.S.A. Ames Research Center (Fig. 28). To achieve the parabolic re-entry speed of 36,000 feet per second and higher, the gun is combined with a shock tunnel. Relative speeds of 44,000 feet per second may be obtained. A limitation of the technique is the small size of the test object, one-quarter inch in diameter.

Some results from experiments in Ames Center facilities are summarised in Fig. 29. The estimated total radiation per unit volume is presented in a form normalised to standard sea level density in the stagnation point region by dividing by the density ratio raised to the 1·7 power. This method is chosen because it normalises the theoretical curves for different densities to a narrow band over the range of densities of interest here. The agreement between experiment and theory appears quite satisfactory for the data points plotted with open symbols.

In these tests, the flow appears to be in thermodynamic and chemical equilibrium. However, as the density was decreased, greater amounts of radiation were observed than the values predicted by the equilibrium theory. These data may be an indication of the non-equilibrium effects. Knowledge of the non-equilibrium radiation picture is limited. Data at this time have largely been obtained from the radiating band system in the visible spectral regions. It is quite possible that significant contributions will be found from the infra-red spectral region.

In addition to the requirement for determining the spectral distribution of non-equilibrium radiation, the so-called "collision limiting" effect must also be studied, since this may result in a reduction in the radiation. At some sufficiently low density, the number of collisions which excite electronic molecular states is no longer large enough to maintain the equilibrium population of the excited states appropriate to the local temperature. As a result, the population of excited states is reduced below its local equilibrium value, and this in turn reduces the magnitude of the emitted radiation. Experiments are presently under way in order to measure the effect of collision limiting at very low densities.

The materials used for heat protection of the spacecraft re-entering at parabolic velocity must be designed to cope with the high heating rates of steep re-entry and the long duration heating of shallow re-entry. The only practicable scheme seems to be the use of an ablation material tailored to these requirements.

The concept of simple ablation is illustrated best by a material like plastic, Teflon, which sublimes at about 1,500°F. (Fig. 30). For this material the released gas thickens the boundary layer and thus blocks the transfer of heat from the hot gas cap. In addition, the various reactions involved in the sublimation process, collectively called pyrolysis, also absorb heat.

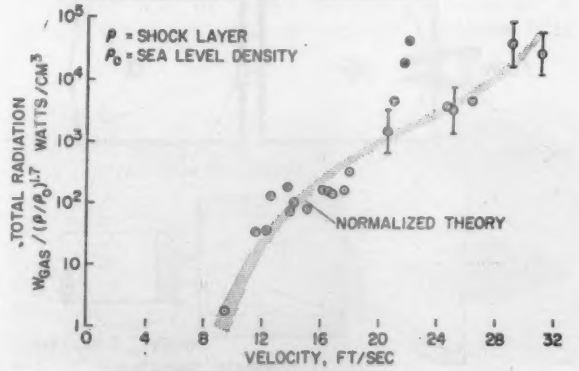


FIGURE 29. Radiation from shock-layer air.

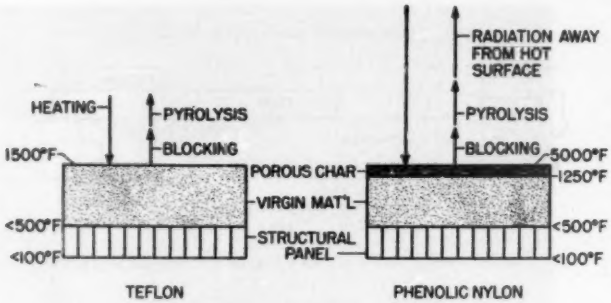


FIGURE 30. Ablation processes.

A more complex class of ablating materials which are composed of phenolic resins and plastics may be of greater interest for re-entry at parabolic velocity. The pyrolysis temperature of such material is low, comparable to that of Teflon, but the presence of the phenolic resin drastically changes the mechanism by which the material ablates. Pyrolysis in this case produces a tough porous, black char which thickens as the entry proceeds. This char has surface temperatures in the 5,000 to 6,000°F range, high enough to radiate as much as half of the heat away from the surface. Ablation of gases continues through the pores of the char, so that the advantage of the blockage is retained. Thus, this class of material is definitely superior to those which do not char.

Naturally, the problem involved here is to improve the char layer. This can be done by the development of advanced materials designed for faster char growth and reduced pyrolysis temperature at the base of the char. This will reduce the amount of virgin material carried along for insulation since this is the major part of the heat protection weight. Improvements in the strength and the integrity of the char are also to be desired.

A vital question to be answered for these materials, as applied to entry at parabolic velocity is, how are they affected by the combined radiative and convective heating? Recently, important answers to these questions have come from research in facilities at the N.A.S.A. Ames and Langley Research Centers (Fig. 31).

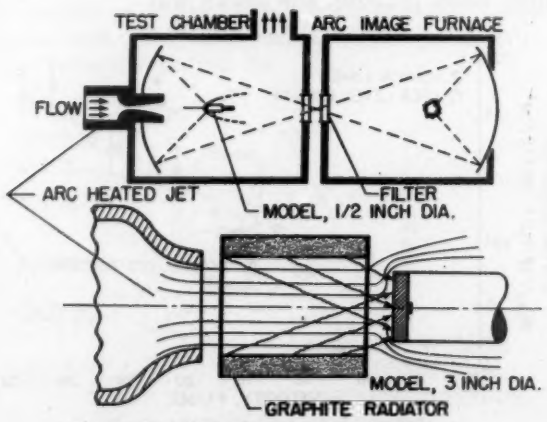


FIGURE 31. Re-entry heating simulators.

Facilities in which this problem is being studied are shown in this figure. One facility focuses the radiative heat from an arc on the test model, which is also heated convectively by a high temperature air jet. The other device is similar except that the radiated heat comes from a graphite cylinder heated electrically. Preliminary experiments indicate that charring ablators are not appreciably degraded by the radiative heating.

4. Structures

Within the entire range of researches that have been introduced by space flight, structures and the materials from which they are fabricated offer the greatest rewards to an imaginative, intelligent, and aggressive research approach. Historically, developments in these areas have been slow and many of our homes are still built by laying brick on brick as in Biblical times. In more modern buildings that use new materials and structural arrangements created without adequate research, neither the heat nor acoustic problems are properly treated. Expenditures in space flight research might be well repaid if only these two problems that are common to housing and space flight were properly solved.

Despite the need for the utmost design refinements in space structures and for the most dexterous matching of materials characteristic to structural arrangement, a proper review of the total effort on these problems might find it lacking. The explanation may lie in a statement by Rhode[5] in 1958, " . . . . . while it has taken man some 50 years to reach flight speeds of 1,000 feet per second, he is now trying to bridge suddenly the gap beween these speeds and values 25 times as large." In 1961 the number is more appropriately recorded as 36 times as large.

Structures erected in space such as a permanent manned laboratory serviced by rendezvous flights provide the opportunity for extreme ingenuity in design. An elementary structure of this type is the Echo sphere orbited over a year ago and still visible in the night sky. Fabricated from 0·0005 in. Mylar the 100-foot sphere weighed only 123 lb. Recent communications from the satellite were of almost the same quality as when it was erected. This satellite may have greater significance as a pioneer in erectable structures than as a communications medium. The programme is to be continued with both objectives in mind.

A 135-foot diameter sphere (Fig. 32) is to be orbited, the skin of which is a sandwich having outer layers of 0·00020 in. aluminium foil and a core of 0·00035 in. Mylar. The skin stiffness is estimated to be 20 times that of the Echo sphere. It is believed that it will not collapse in space even if punctured with meteoroids. The aluminium outer foil should protect the plastic from ultra-violet radiation.

The large wheel-like structures depicted in the Sunday supplements, slowly rotating in space to provide an artificial gravity environment to the manned occupants, may indeed be possible. With the growth in launch vehicle dimensions, problems of storing the erectable structures will diminish and strong points for resisting the erection loads of heavy equipment can

FIGURE 32. 135-foot diameter rigidised sphere with canister.

possibly be provided. Erectable structures, although fascinating, occupy only a small corner of the problem field.

The structural loads on launch vehicles or re-entry spacecraft systems are applied from many sources, some of which may be outlined as follows:

Static:

Thrust and drag.

Normal control forces and aerodynamic lift.

Dynamic:

Wind shears (including short wavelength shears).

Gusts.

Dynamic response of structure (including coupling with control system).

Fuel sloshing (including coupling with structural and control-system dynamics).

Buffeting (excitation of local structure).

Panel flutter.

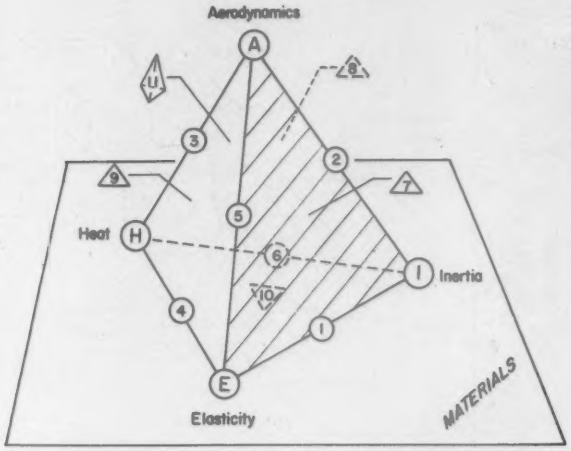
Flutter.

Acoustic excitation (local modes—fatigue).

Engine vibration.

Superimposed on the more conventional load sources is aerodynamic heating which produces thermal stresses and reduces the strength and stiffness of the structure at elevated temperatures, thereby increasing its susceptibility to dynamic problems. These involved interactions among aerodynamics, elasticity, inertia, and heat have been described by Garrick[6] with the tetrahedron representation in Fig. 33. It can be seen that Collar's aeroelastic triangle of 15 years ago[7] now includes only a part of the total and his title, "The Expanding Domain of Aeroelasticity" might be borrowed and increased to "The Expanded Domain of Thermo-aeroelasticity."

The heating problem and the materials for the heat shield at the nose of a blunt body re-entering a parabolic path have already been briefly mentioned. Surfaces behind the nose will generally experience lower heating rates and lower temperatures than the nose region. Structures and materials for these areas are being studied and Heldenfels of the Langley Research Center in a recent paper[8] described some of the interesting possi-



1 Vibration
2 Stability
3 Aerothermodynamics
4 Thermoelasticity
5 Aeroelasticity, static
6 Thermal molecular processes
7 Aeroelasticity, dynamic
8 Stability & heat
9 Aerothermoelasticity, static
10 Vibration & heat
11 Aerothermoelasticity, dynamic

FIGURE 33. Aero-thermoelastic tetrahedron.

bilities (Fig. 34). The basic difficulty in this problem arises from the wide range of heating rates and total heat inputs that can occur as re-entry is made along different paths in the corridor. A high heating rate and a low total heat input which occurs in a sharp re-entry along the bottom of the corridor might require the use of a low temperature ablating structure to achieve minimum weight. A high total heat input with a low heat flux rate for a low g re-entry along the top of the corridor may be more efficiently accommodated with an alternative structure. Currently the weights of all the thermally protected surfaces are high and some of the goals toward which research is being directed are shown in Fig. 35.

The dynamic loading and structural response of the launch vehicle provides another fruitful area for research. Several failures of United States satellites can be traced to inadequate analysis of the dynamic stresses occurring during launch.

As the sizes of launch vehicles are increased to provide thrust for advanced missions, problems from

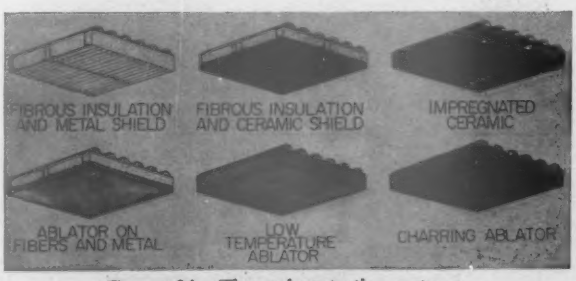


FIGURE 34. Thermal protection systems.

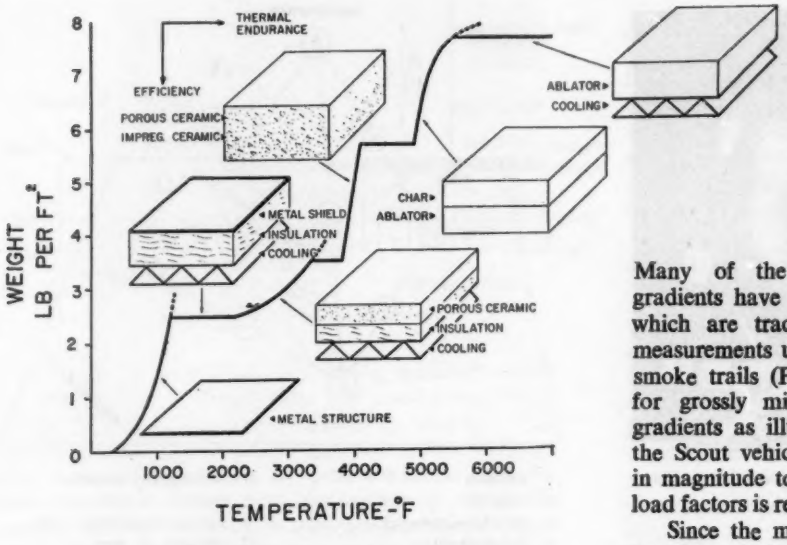


FIGURE 35. Research goals for thermal protection weight.

fuel sloshing, interactions between the elastic vehicle frame and the controls, and from the wind gradients and wind shears will become more difficult.

Recent studies of fuel sloshing[9] show excellent agreement between theoretical and experimental values for the sloshing frequency and for the force exerted by the sloshing liquid. For a spherical tank the oscillating force is proportional, as might be expected, to the weight of liquid in the tank, and is at a maximum at the first fundamental frequency of the tank when it is half full.

The frequency of the first mode decreases with increase in tank radius ($f \sim (1/\sqrt{R})$ which leads to the dangerous possibility of resonance with the elastic frequency of the vehicle structure and saturation of the controls. Baffles for the fluid damping of large vehicles are obviously required and the solution of this problem for varying levels of the tank fluid is under active investigation.

The dynamic problems from wind gradients and shears are more complex and involve the vehicle configuration as well as the attitude control mode used along the flight trajectory.

A first problem with wind gradients is establishing values for them that can be used with confidence in design. Many of the available statistical data on wind gradients have been obtained using sounding balloons which are tracked by a theodolite. More accurate measurements using photographs from three stations of smoke trails (Fig. 36) show that the possibility exists for grossly miscalculating the stresses due to wind gradients as illustrated by the sample calculations for the Scout vehicle (Fig. 37). A research effort similar in magnitude to that required to establish aircraft gust load factors is required in this area.

Since the maximum wind gradients and maximum aerodynamic forces (max. q) occur at about the same time in the flight, angle-of-attack changes due to the wind gradient lead to high dynamic loads. Geissler[10] describes methods for reducing vehicle structure loading and control requirements by turning the vehicle into the wind to reduce the angle of attack and resulting dynamic stresses. The addition of stabilising tail surfaces to furnish essentially neutral vehicle stability for the critical flight conditions alleviates the stress and control problems, but for large vehicles is expensive in weight and adds the design problems of the large surfaces and their vehicle attachments.

The use of swivelling rocket motors for providing control and stabilising movements, as is the practice in many large vehicle designs, appears far less attractive when applied to the large multi-stage space vehicles required for the future. The rocket engines are grossly complicated by the requirement for flexible propellant lines to the engines, gimbal bearings and, in the multi-engine case, by the requirement that openings be left in the engine compartment heat shield to provide for the motion of the nozzle. Elimination of rocket-engine

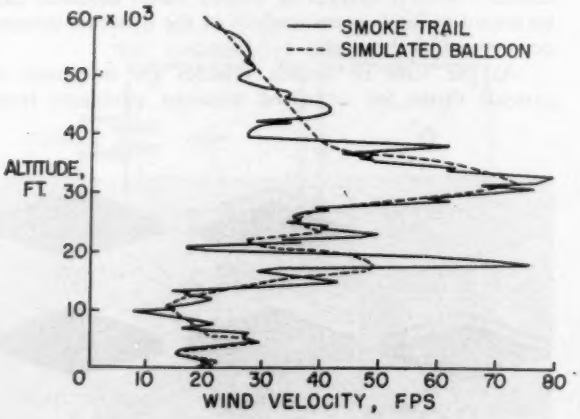


FIGURE 36. Wind-velocity measurements.

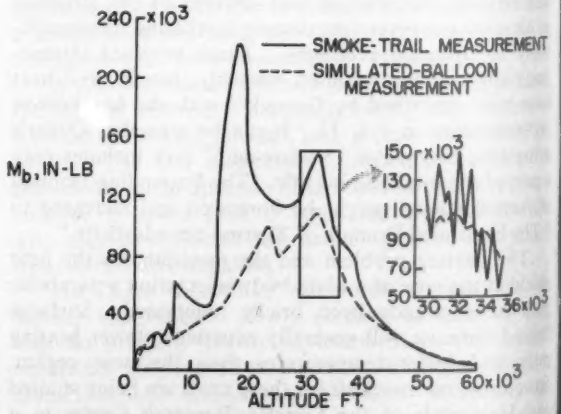


FIGURE 37. Bending-moment envelope due to winds.

swivelling on large space vehicles in the author's opinion would provide one of the greatest potential opportunities for improving the reliability of space flights. The basic space vehicle is statically and dynamically unstable with the centre of pressure high above the centre of gravity while the engines that provide the controlled stability are much closer to, and below, the centre of gravity. The possibility exists for using controlled canard surfaces located near the centre of pressure of the aerodynamic forces for flight through the atmosphere, and jets at the nose of the vehicle for control during the initial launch period and in space flight. These systems and others require careful investigation if the vehicle structural designers are not too heavily penalised by an unimaginative approach in the control area.

5. Concluding Remarks

The goals of space flight are ambitious ones. To achieve them a vast new technology must be created on the base of what is known. This technology is a challenge to the creative, devoted efforts of scientists and engineers who seek to understand the universe and from it make possible a better way of life for all men.

REFERENCES

1. NEWELL, A. F. (1961). An Appreciation of Missile Structures. *Journal of the Royal Aeronautical Society*, Vol. 65, No. 607, July 1961.
2. SMOLAK, G. R. and KNOLL, R. H. (1960). Cryogenic Propellant Storage for Round Trips to Mars and Venus. Paper No. 60-23, Institute of the Aeronautical Sciences, January 1960.
3. MCCRAKEN, C. W., ALEXANDER, W. M. and DUBIN, M. (1961). Letter to the Editor, *to be published in "Nature,"* 1961.
4. KIVEL, BENNETT (1959). Radiation from Hot Air and Stagnation Heating. Avco-Everett Research Laboratory Research Report, 79, AFBMD-TR-59-20, October 1959.
5. RHODE, RICHARD V. and HOUBOLT, JOHN C. (1958). The Impact of Space Technology on Research and Development—Structures and Materials. Presented before the General Assembly of the Advisory Group for Aeronautical Research and Development, NATO, Copenhagen, Denmark, 20th-29th October 1958.
6. GARRICK, I. E. and CUNNINGHAM, H. J. (1961). Problems and Developments in Aerothermoelasticity, presented at the Symposium on Aerothermoelasticity, Aeronautical Systems Division, AFSC, Dayton, Ohio, 30th October-1st November 1961.
7. COLLAR, A. R. (1946). The Expanding Domain of Aeroelasticity. *Journal of the Royal Aeronautical Society*, Vol. 50, No. 428, August 1946.
8. HELDENFELS, R. (1961). Structures for Manned Entry Vehicles. Presented at AFOSR Conference on Aerodynamically Heated Structures, 25th-26th July 1961. Arthur D. Little, Inc.
9. STOFAN, ANDREW J. and ARMSTEAD, ALFRED. An Analytical and Experimental Investigation of Liquid Oscillations in a Spherical Tank. National Aeronautics and Space Administration Technical Note, *in preparation.*
10. GEISSLER, ERNST D. (1960). Problems in Attitude Stabilization of Large Guided Missiles. *Aerospace Engineering*, Vol. 19, No. 10, October 1960.

Sir Owen Jones: In accordance with tradition there was no discussion after the Wilbur Wright Memorial Lecture, but he would call on Mr. B. S. Shenstone, President-Elect of the Society, to propose a vote of thanks.

Mr. Shenstone: Dr. Silverstein had certainly fulfilled the great tradition of the Wilbur Wright Memorial Lecture. He had given them a wide view of an enormous subject and it had been quite uncluttered with tools of the trade, such as mathematics and, also without the mass of what so many speakers mistakenly considered relevant detail. He thought that much of Dr. Silverstein's material was new to a great many of those present; it was strange and exciting, not to say, "out of this world." The typical problems he had discussed would have been impossible of solution only a short time ago, and yet, now they realised that they could be solved, and they were worthy of solution, for the sake of voyages of discovery—so much more worthwhile than for voyages of destruction. Christopher Columbus' equipment was the result of, perhaps, 2,000 years of undirected effort. Here they had the opposite, except that for both of the projects, Columbus' and Dr. Silverstein's, the finances were only forthcoming by begging, whether it be at a throne, a Congressional Committee, or a non-technical, non-political nonentity in a treasury. But they now had the well-directed, modern method typified by Dr. Silverstein himself and he had great pleasure in proposing their vote of thanks for his great review.

Following the Lecture a reception was held at 4 Hamilton Place.

Bird Flight and The Aeroplane*

BY

J. WILDING

(*Chester Branch*)

IF MAN'S desire to fly was not totally inspired by the flight of birds at least his early attempts at heavier-than-air flight were a direct imitation of birds. To the earliest known aviators two features seemed indispensable in any flying machine, wings that flapped, and wings covered with feathers. The former at least seems reasonable, but no attempt was made to discover the purpose of feathering a bird's wing and feathers were used simply to give the flying contraption the appearance of a bird. As we shall see later these factors probably delayed the advent of sustained flight—not necessarily powered—by many years.

Imagination has always, in the past, attributed the bird with greater powers than it really possessed. Many early flying machines were designed as chariots borne by as few as six doves—powerful indeed! Its powers to soar so high that it became lost to sight gave it the status of a semi-deity, from which came the mariner's faith in the albatross, perhaps. It may well be that the association of flight with the supernatural discouraged many would-be fliers, but nevertheless from the wilderness of the legendary Icarus and the "tower-jumpers" has emerged eventually the science of aeronautics.

The first true aeronautical engineer would seem to have been Leonardo da Vinci (1452-1519) who, besides beating Newton to his third law of motion by 200 years, also designed a feasible parachute, a not-so-feasible helicopter, and an ornithopter. Unfortunately, the only drawing still in existence of the ornithopter is a detailed sketch of the flapping mechanism, while the design of the wings might have proved much more instructive. His ornithopter seems to have received more serious consideration, by reason of the more detailed drawing, than the helicopter, showing that even such a brilliant inventive genius as Leonardo was still obsessed with flapping to provide flight, as opposed to the "controlled descent" of his parachute.

Modern aeronautics owes its rapid advance to Cayley and Lanchester. Once man tore himself away from the obvious desire to flap wings, and was prepared to copy first the birds in gliding flight only; becoming reconciled, mixing metaphors, "to learning to walk before running," the ultimate goal of controlled, sustained flight was assured. This vital step, at first sight, appears to be a step away from "natural flight." However, it is interesting to note that, by making this move and attacking the problem from a more logical and practical angle, we arrive at the same answers as did nature in the process of evolution. Sir George Cayley, it has recently come to light, designed a successful glider in 1852 or 1853; in performance and wing plan it compares perfectly with the flying squirrel in having a wing loading of about $\frac{1}{2}$ lb./ft.^{2} and gliding angle of one in six. In 1897 S. P. Langley of the Smithsonian Institute designed an aircraft, steam driven, with an airframe based on a bird's skeleton; ridiculous at first sight but, as we shall see later, man eventually arrived at the same answer in some structural problems. Our rejection of feathers as being necessary for flight, which would have been little short of heresy to the earliest would-be aviators, is simply a précis of an evolutionary process. The earliest flying creatures, such as the pterodactyl, certainly did not use feathers (which were probably originally used as a form of insulation anyway); neither do bats or insects of the modern age, their less spectacular flying probably passing unnoticed. Man's parallel development to the evolution of feathers as a peculiarity to the airborne species of animal would seem to be the diversity of flaps, slots and other specialised pieces of "ironmongery" that he delights in draping from his aircraft.

To appreciate the analogy between bird and aeroplane flight it is necessary to know the basic construction of the wing of a bird, Fig. 1. From this diagram we can see that the wing is of the same basic construction as the human arm, the feathers being borne by the lower arm and the "hand," with the small ala spuria, or "bastard wing" constructed as a "thumb." The feathers on the hand are known as "primaries," and those on the lower arm "secondaries." A membrane of two layers of skin known as the patagium stretches between "shoulder" and "wrist," which prevents complete extension of the wing, thus limiting the maximum wing area and spread of the feathers carried on the lower arm. In all types of flight these two groups of feathers provide the lift, the primaries also being used for control surfaces: bird flight can be divided, for the purpose of analysis, into two main sections, gliding flight and flapping flight. The latter division covering normal "powered" flight, take-off and "aerobatics," which are usually special manoeuvres used in catching prey, or combat. The former also covers landing and soaring.

For comparison with aeroplane flight, flapping flight can be ruled out, but as a means for man powered flight it still seems to be receiving serious consideration in some quarters, although at least one group working on man powered flight, that at Queen's University Belfast, has

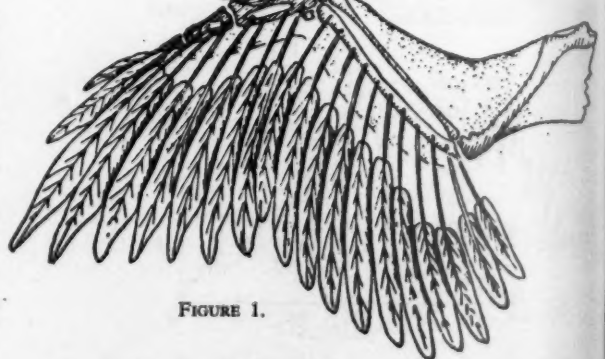


FIGURE 1.

*21-26 *Years of Age Group.*

rejected this mode of propulsion and support as being too inefficient at relatively high speeds, due to excessive vortex formation. However, in his article in the "New Scientist" for 24th December 1960, Nonweiler, one of the design team, admits that "tricks can be played" by twisting and flexing the wings, thus limiting the air resistance and losses associated with vortex formation, but that the effects are not fully understood and an additional weight penalty would result. Thus it appears that one important factor for the rejection of the ornithopter is ignorance of the mechanisms of flapping flight. With modern cinematograph techniques the zoologists have learnt an appreciative amount about flapping flight which might well be used to advantage when considering such projects.

The same basic principle cycle appears to apply to both feathered and unfeathered skin membrane wings, but the feathers increase wing efficiency as a much lower frequency of flapping is required to keep a bird airborne than a bat or butterfly of similar wing loading.

In normal "cruising flight" the propulsion power is provided by the primary feathers in the main, the flapping is a "wrist" action (remembering the analogy between wing construction and the human arm). The secondary feathers provide a fairly constant lift value, while the primaries provide the propulsion power and a varying degree of lift. Fig. 2 shows the locus of the wing tip and wrist joint, in normal flight, of a seagull. The graduations on this tracing show equal time intervals. We can see that for the whole of the cycle the wrist joint is out-of-phase with the wing tip, the wrist being slightly in advance of the wing tip. We can see also that the upward beat is faster than the downward. It must be remembered that these loci are relative to the bird, which does not itself travel at a uniform forward velocity during any cycle, but (in level flight) accelerates and decelerates in a horizontal direction, and falls and rises vertically with each wing beat. The resultant action of the wing is thus a mixture of gaining lift from the downbeat (1 to 15), in much the same way as an oar propels a boat, from the reaction of the primary feathers against the air; this downbeat may be with a slight negative angle of incidence (relative to fore-and-aft axis of bird) thus giving a propulsive component of thrust, especially during the latter part of the downbeat. Beween points 15 and 20 an appreciable change in the angle of attack of the wing occurs, as the wing is brought upwards and forwards (remember that the origin of the curve is itself moving forwards) at a positive angle of attack. From the wrist locus, at point 20, it is seen that the outer wing receives a "flick" forward during which the wing twists, giving a "propeller" effect

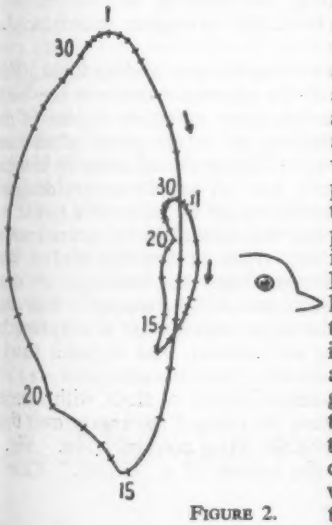


FIGURE 2.

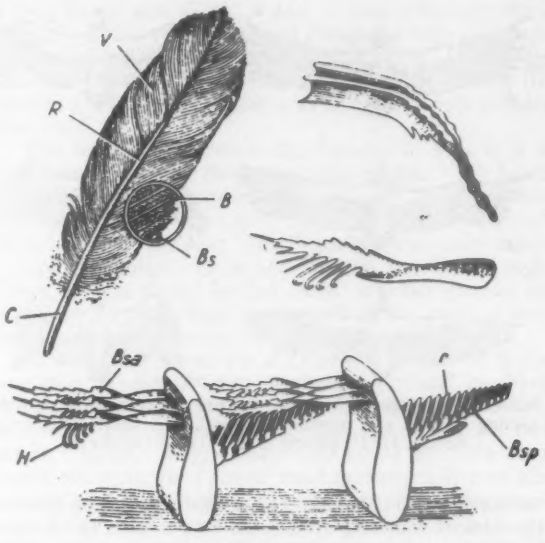


FIGURE 3.

while the angle of attack again changes in preparation for the next downbeat.

In this description of the cycle the effect of feathers has not been mentioned. Their function is, as mentioned earlier, apparently to raise the efficiency of the wing, as opposed to a fundamental component of a practical wing. During certain parts of the cycle the wing will be travelling with a negative angle of attack, *i.e.* for a normal, impermeable wing, it will experience negative lift. This resistance is reduced to a minimum by the use of innumerable valves mounted in sections, which we call feathers.

From Fig. 3 the feather consists of a shaft *R* with a set of barbs *B* forming the "vane" of the feather. Between the individual barbs are sets of barbules, B_s on the inset, which are shown enlarged below. The barbs themselves are of an exceptionally clear aerodynamic section, looking rather like a set of stator blades from a gas turbine, which is not inconceivable since the duty of the barbs is the same. From this drawing the arrangement of the barbules as "non-return" valves can be seen. If we consider an upward air flow past the feather, the anterior barbules, B_{sa}, which are quite flexible in the plane of the section, are raised and the hooks, *H*, are disengaged from the ridges of B_{sp}, and resistance to the air flow reduced considerably. A downward air flow through the system, however, impinges on the upper surface of the anterior barbule, which is itself engaged in the ridges of the posterior set. The posterior barbules are quite rigid and an effective seal is formed producing a near impermeable surface to the air flow. Any air leaking past the tips of the anterior barbules is flowing past a section of barbs which will produce high drag when the flow separates at the blunt end at what is now the trailing edge of the barb.

Having considered the normal cruising flight of the bird, wing flapping mainly for propulsion, while the inboard section is producing most of the lift, let us look at a typical wing action during take-off. The total lift must now be supplied by the wing motion so the whole wing now flaps from the "shoulder." The amplitude of the wing stroke increases, and the direction of the wing

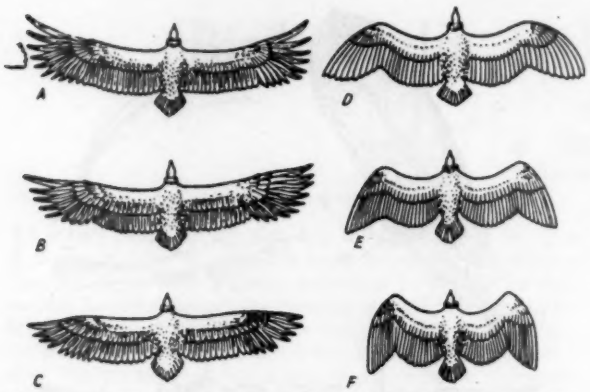


FIGURE 4. Wings of vulture (*Gyps*). (*A*) Soaring upwind, gaining height; (*B*) upwind on level; (*C*) downwind, losing height; (*D-F*) gliding flight. (After Ahlborn.)

movement also changes. The stroke begins with the wing tips almost touching behind the bird's back, the primary feathers are spread forming several separate lifting surfaces, the bastard wing is usually clear of the main wing, forming, in effect, a slot on the leading edge. The wings are now swept forward until they meet in front of the bird's head. They then strike backwards and upwards, during which movement the "valve operation" of the feathers is important, restricting wing drag to a minimum. At the end of the backward stroke the primaries are given an extra "flick" to provide a vertical "thrust" in much the same way as a fish's tail propels it through the water. In fact, most of the lift comes from the forward sweep, which occurs at a large positive angle of attack, with the wing moving horizontally, similar to the rotor action of a helicopter.

It is in the action of landing that the similarity between bird and aircraft can be seen, perhaps, most clearly. Landing is easily observed—seagulls on the pier, sparrows touching down on the lawn—all birds use the same technique. The approach begins with a glide, legs tucked away, primary feathers extended to give maximum lift at a low speed and the tail partially spread, and being used as a balancing control for direction and attitude. As the bird proceeds on its glide path, minor adjustments of speed and rate of descent are made by slight alterations in wing area by closing or opening the primaries, or a quick flap to reduce the rate of descent in much the same way as a pilot uses a short burst of power from his engine. As the required point of touch-down is approached legs are lowered and thrust slightly forward to reach for the branch or rock, and to provide braking. The bastard wing is extended as the bird's trim is changed to nose up as the "round out" of landing begins. In this manoeuvre the bird has to be much more precise than any conventional aircraft, it has not simply to touch down somewhere near the downwing end of a long, broad landing strip, but to land gently on a very small target, with no forward speed. The final braking is affected by lowering and spreading the tail as the bird drops, often with a final beat of its wings, on to its perch. Still, or almost still, air has been assumed here; the problem is, of course, much simplified if the local air speed is such that the bird can fly easily up to the perch and merely decelerate to the wind speed, thus having zero ground speed at the required point. Other aeroplane-like tricks are used to facilitate an accurate

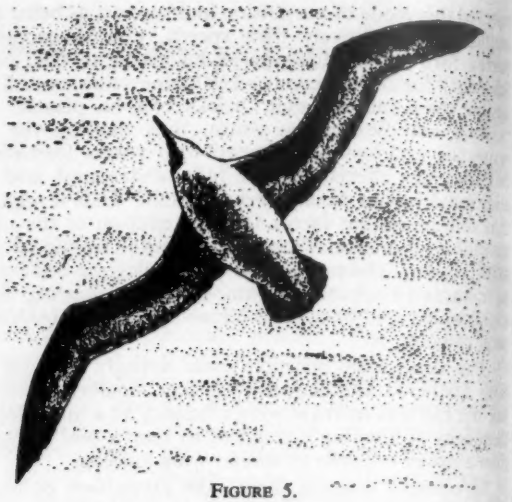


FIGURE 5.

positioning on landing, sideslipping, or, as Professor Young claims in his book, the old fighter pilot trick of a roll to lose height.

Finally we come to soaring and gliding flight. This must, of course, be of the greatest interest to the fixed-wing aeronaut. It is said that imitation is one of the sincerest forms of flattery, so surely glider pilots have paid buzzards and eagles a great compliment by sharing upcurrents with them! Just as sailplanes are designed to give a maximum performance by being able to use the gentlest of upcurrents to maintain altitude, so are soaring birds. The first of two types of soaring bird is that which utilises upcurrents due to thermals or wind deflected by large objects such as land masses. This class of soarer flies in the same manner as a sailplane by circling in the rising air column, and includes hawks, buzzards, kites and vultures. Their characteristics are a low aspect ratio, and an ample supply of slots, with a broad tipped wing. They have the distinct advantage over their aircraft rivals of variable wing configuration. Fig. 4 shows a vulture in the course of a "circuit." Case *A*

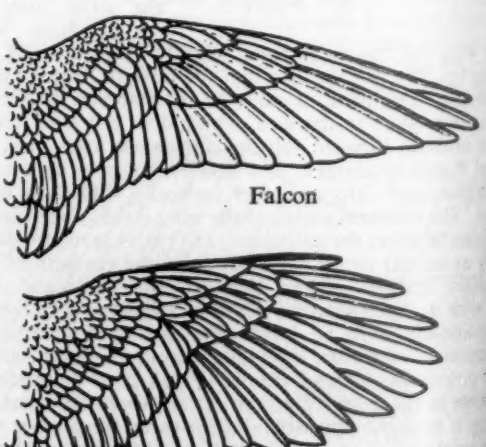


FIGURE 6.

FIGURE 7.

shows the wing plan when soaring up-wind and gaining height; in this case the aspect ratio is approximately 8, and the primaries are fully spread to give maximum lift. When level flight is required, case *B*, the primaries are closed partially to reduce lift; an action which is more marked in the down-wind, losing height, case *C*. The other three cases show the remarkable flexibility of the wing plan, the aspect ratio drops to a figure of about three in the final one, on normal gliding flight.

The second soarer is that relying on the wind gradient as its source of energy. The perfect example of this type of bird is the beautiful albatross, Fig. 5. This mode of soaring seems to be restricted to sea birds, as the wind gradient is more uniform over a homogeneous surface such as the sea, and above which thermals are likely to be very rare. The technique involves flying down-wind, losing height with wings swept back, then turning back into wind and gaining height, the wind speed increasing with height, with wings swept forward. As soon as the maximum "free stream" wing speed altitude has been reached (usually at about 50 ft.), the bird turns down-wind and repeats the cycle.

While these soarers have different aspect ratios, the albatross having an aspect ratio of over 20, all soaring birds have one structural characteristic. It was mentioned earlier that normal cruising flight relies upon the inboard "lower arm" section of the wing for its pure lift while the wrist outwards provided propulsion. Thus the soarer has a long lower arm (Figs. 4 and 5) and relatively short "hand." If this type of wing is compared with one built primarily for speed, such as the falcon's, Fig. 6, it will be seen that the wing is pointed, with not much facility for spreading its primary feathers as slots, and with a short lower arm.

The wing shown below the falcon's in Fig. 6, is a compromise between these two types of bird. The hawk is capable of great speed, and also of quite efficient soaring. It has the low aspect ratio and wing tip plan of the vulture, and the long "hand" section with short lower arm of the falcon. Generally we can say that a high aspect ratio is found in fast birds, whether soarers or essentially flapping flight birds, such as the swallow and swift. A low aspect ratio is confined to land soarers.

As with aeroplanes the duty of a bird can be fairly accurately predicted from its wing form and its wing loading. The bird had its slots and flaps, airbrakes, retractable undercarriages and, dare one say it, the bat had its "radar," long before man could fly. We may have flown faster than sound but has man really won the battle of low-speed flight? We have our blown flaps and Short S.C.1's but all use methods of taking-off which are rejected once airborne and prove deadweight. The bird's wing provides lift and power for all flight conditions. Structurally the bird is hardly inferior to the aeroplane; Fig. 7 shows the metacarpal ("hand") bone of a vulture, a design which few aircraft structural engineers could better for strength-weight ratio, so perhaps Langley was not so far out in 1897.

Nature and man seem to have arrived at the same answer independently in so many instances that it might well profit the "short take-off and landing" brigade to study a little closer the aerodynamic lift devices of birds. Perhaps the flexible primary feathers reduce induced drag, perhaps the positioning of the bastard wing is designed to separate two different flow patterns over the secondary and primary feathers. Who knows?

The Development of Tailless Aircraft and Flying Wings*

BY

W. BISHOP

(*Brough Branch*)

Introduction

The tailless aircraft configuration is relatively rare in the field of aircraft design and for many years was regarded as a "freak" design. It is intended to trace the development of tailless and flying wing aircraft and to outline the major problems in control and stability.

First it is necessary to arrive at an arbitrary definition of the term tailless aircraft. Later an attempt will be made to classify the different tailless types in detail, but for the moment it is sufficient to regard a tailless aircraft as "an aircraft having no auxiliary horizontal stabilising plane, deriving lift and controlling moment solely from the main plane." This definition, as it stands, includes what are often termed flying wing aircraft.

**Under 21 Years of Age Group.*

It will perhaps be helpful to introduce the basic control system for tailless aircraft (*see* Fig. 1). The tailless aircraft differs from the conventional machine in that it combines the duties of two control surfaces into one; the duties of the elevators and ailerons are combined in the elevons, which act together as elevators and differentially as ailerons. Directional control is exercised by tip rudders or drag rudders of some form. This explanation is approximate but serves to indicate the basic differences between the tailless and conventional aircraft and to introduce terms which will be used in the paper.

What features of tailless aircraft have appealed to aircraft designers? Broadly, they can be classified into three groups:

(*i*) Designers who chose the tailless layout for

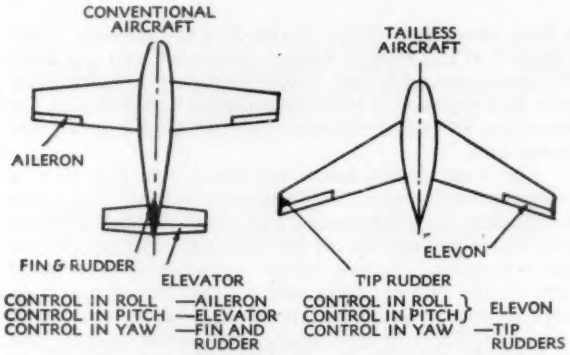


FIGURE 1. Control system for tailless and conventional aircraft.

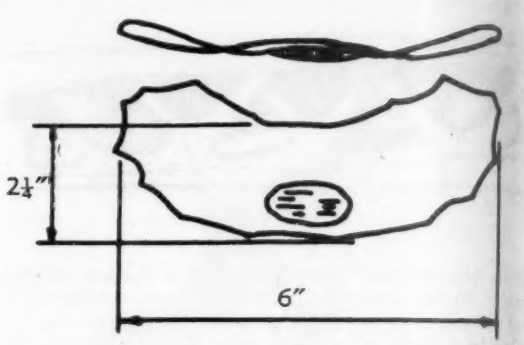


FIGURE 2. Zanonia seed-leaf. Weight 2 oz.

reasons of stability. These designers were seeking to devise a quite inherently stable aircraft, that is, an aircraft which returns automatically to its normal flying attitude after a disturbance, without resorting to automatic mechanisms or controls. The designs of J. W. Dunne come under this heading.

(*ii*) Designers aiming at design for controllability and manoeuvrability during abnormal flying conditions. The possibility of having an aircraft free from spin and stall prompted work in this direction. Adherents of this design class included Hill and Arnoux.

(*iii*) Designers who regard the tailless aircraft, and more so the flying wing design, as ideal in structure and performance. Less profile drag will result from a flying wing layout and gas turbine and pusher airscrew power units can be used to full advantage. Another performance factor in its favour is that it lends itself well to laminar flow design. The efforts of Horten, Lippisch and Northrop have been directed towards these ends.

History

On 12th September 1906 on the lonely island of Lindholm the Danish pioneer J. C. H. Hansen-Ellehammer first flew his tailless biplane. This was one of the earliest recorded free-flights made in Europe. The aircraft was an unusual high-wing tractor biplane which employed an early form of automatic longitudinal control which depended for its action on the pendulum effect of the pilot's body. The pendulum, to which the pilot's seat was attached, was coupled to a control surface on the lower wing. Although this design was of interest, Ellehammer later turned his attention to more conventional aircraft.

It is strange that a Javanese member of the cucumber family of plants should have any bearing on the story of tailless aircraft, but this is so. The species of cucumber is the Zanonia Macrocarpa (*see* Fig. 2). The leaf of this plant is the interesting feature. It is kidney shaped with bent up tips and consists of a hard seed-kernel surrounded by fibrous tissues. The stable gliding properties of this seed-leaf caught the attention of certain German naturalists, and as a consequence papers were published and discussions took place between naturalists and aeronautical enthusiasts. However, little ensued from these discussions until they came to the notice of Ignaz and Igo Etrich. The Etrichs, who had been experimenting with gliders, adopted the zanonia seed-leaf idea and by 1906 Etrich gliders were making flights of 250 yards or more. The only control the pilot had over his machine was by leaning to one side or the other, so directing the glider. Efforts to fit a power unit to this design proved to have harmful effects on stability, so Igo Etrich decided to fit a normal Penaud type of tail to his design. This new design developed into the well known "Taube" monoplane, which was characteristic of German aircraft design up to 1914.

Dunne, The English Pioneer

In England, an early pioneer of tailless aircraft design was J. W. Dunne. Dunne was a far-sighted and gifted designer who had a better grasp of stability problems than many of his contemporaries. His design incorporated wing sweepback coupled with a marked wash-out towards the wing tip. Wash-out on the wing means that the angle of incidence of the aerofoil section decreases towards the wing tip. Dunne's 1910 biplane was powered by a 50 h.p. Green engine, mounted behind the pilot, driving two pusher airscrews by means of a chain drive. This machine was representative of all the Dunne biplanes, in that it had no stagger on the wings, no dihedral, and a sweepback of about 30°. The upper and lower wings were joined at the tips by end-plates,

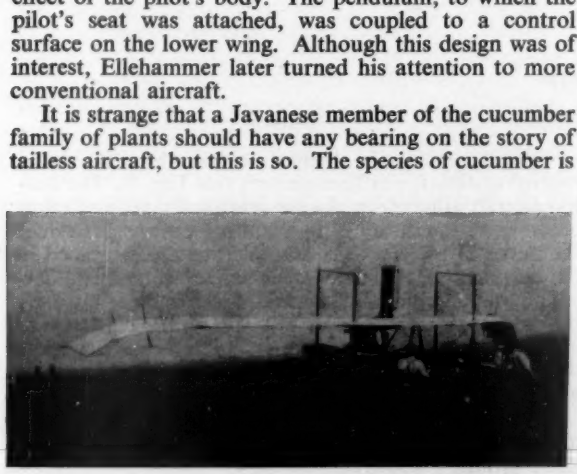


FIGURE 3. Dunne 1911 Monoplane.

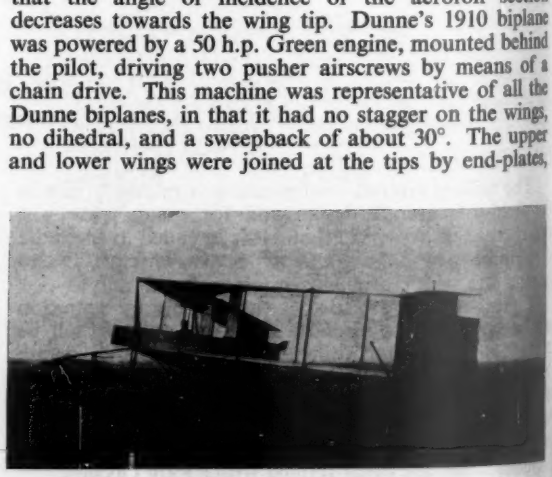


FIGURE 4. Dunne 1912 Biplane.

which served as fins, and control was provided by aileron-like surfaces at the trailing edge of all wings. The pilot's control system consisted of two levers, one to his right, the other to his left, each lever moving its respective controllers. These levers could be locked in various positions which indicated the extent to which Dunne relied on the inherent stability of his aircraft, the controls serving only for voluntary changes of flight pattern.

The Dunne 1911 monoplane with its diffuser type wing tip, was a definite improvement in design (Fig. 3). Diffuser wing tip was the name given to wing tips of downswept form with a positive rake on the tip. The new wing, with its thick and more stable section, was joined to an undercarriage of reasonable design.

It is a pity that, owing to official policy regarding monoplanes, Dunne had to return to biplane design. The Dunne biplane shown in Fig. 4 is characteristic of his later biplanes. The aircraft was powered by a stationary engine driving a pusher airscrew and sweepback and wash-out are clearly visible; also a slight amount of anhedral is apparent. Due to ill health, Dunne gave up his aeronautical activities in 1913. We have a great deal to thank him for, especially in our knowledge of stability and control of tailless aircraft. Perhaps, if Dunne had not been compelled to give up his work, we in this country would have had a more rapid and less erratic movement towards the ideal flying wing.

French Tailless Aircraft Progress

Less well known than Dunne, was the work of a French aeronautical engineer, Réné Arnoux which from 1910 to 1922 concerned tailless aircraft that differed greatly from Dunne's configuration. The Arnoux tailless aircraft employed a rectangular plan form wing, with no sweepback and no wash-out, depending for its stability on the reflex camber of the wing section. Control was maintained by means of full-span controllers which had to be fitted with stops in order to prevent their downward movement changing the reflex camber to normal camber, thus upsetting the stability. A series of monoplanes and biplanes of this configuration was built during the 1910-1922 period. The final design was a racing monoplane (Fig. 5) designed and built for the 1922 Coupe Deutsch air race and powered by a 320 h.p. Hispano-Suiza engine. A symmetrical aerofoil section was selected for this design together with full span controllers. The pilot sat in an aft position, visibility being further impaired by a radiator mounted just forward of the cockpit. The prototype crashed on the first test flight and was destroyed. This discouraged Arnoux from further investigation into this design.

Another French aircraft intended for the Coupe Deutsch was a tailless machine with swept forward wings, having wash-in towards the tip; that is, progressively larger incidence towards the tip (*see* Fig. 6). This system is longitudinally as stable as the Dunne system. The sweep forward was so arranged that the ailerons were forward of the c.g. and the elevators aft of the c.g. The aerofoil section was again symmetrical. Wind tunnel tests, conducted on models, indicated satisfactory longitudinal stability up to the stall, but this aircraft was never completed.

Another example of this type of tailless aircraft was built in 1944 by the American Cornelius Aircraft Company. The separation of aileron and elevator on the

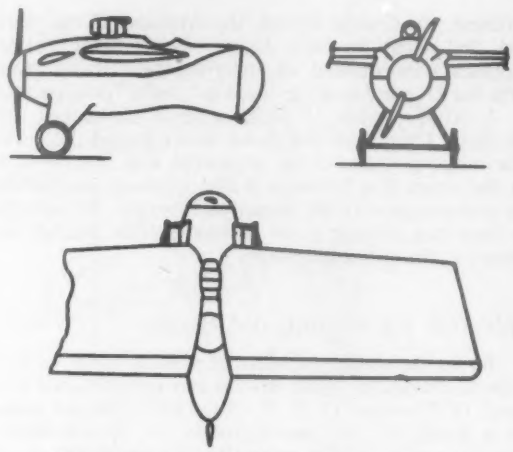


FIGURE 5. Arnoux 1922 Racing Monoplane.

trailing edge was retained, but a pronounced taper of the wings was introduced. Three experimental gliders were built and flown, but no further development followed.

Lippisch and the Delta Design

Meanwhile in Germany, an aeronautical engineer, Alexander Lippisch, was occupied with the idea of flying wing aircraft. His experiments met with little success until in 1925 he was given a post as designer for the German Research Institute for Soaring Flight. Here with a series of flying models and wind tunnel tests, he evolved a successful series of tailless gliders; for Lippisch, these gliders were only a stepping stone to the large flying wing he intended to design one day. It appears that he investigated all three approaches to the

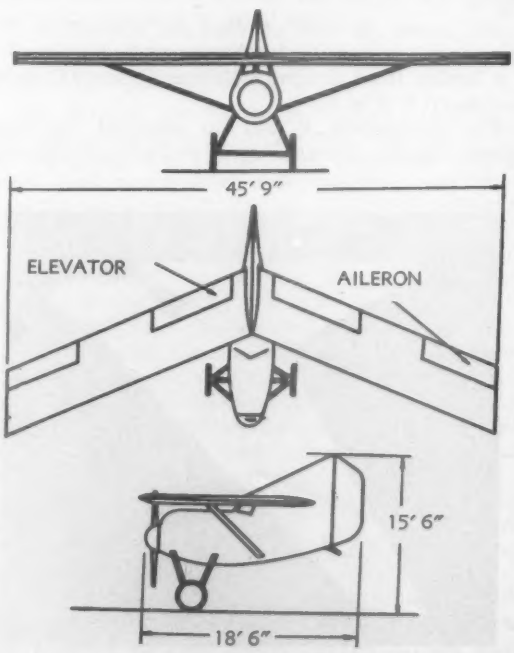


FIGURE 6. Swept Forward Wing Racing Monoplane.

problem, the Dunne layout, the Arnoux "flying plank" and the swept forward design. After some research Lippisch concentrated on merging the "flying plank" with the Dunne layout to form a "Delta" configuration.

A whole series of Delta aircraft developed from the Delta I was built and flown in the period 1931-1937. The initial promise of the prototype was not borne out by the series that followed it and Lippisch later severed his connection with the Research Institute. He appeared to have lost interest in his tailless designs, but his work comes to the fore again later.

Hill and the Pterodactyl Series

By far the greatest amount of publicity enjoyed by the tailless aircraft in Great Britain can be attributed to the work of Professor G. T. R. Hill. Hill's designs evolved as a result of his investigations on maintenance of stability and control at normally uncontrollable attitudes of flight, as exemplified by maintenance of control beyond the stall. Unlike Dunne, who tried to build an inherently stable aircraft, or Lippisch, with his idea of the large flying wing, Hill wanted to design an aircraft incapable of being out of control.

Hill's original system of control consisted of a moving wing tip controller which automatically adjusted itself to a neutral position, regardless of the aircraft's attitude. In this manner the control surface never reached stalled condition and thus lateral and longitudinal control was guaranteed under all circumstances. The wing itself incorporated sweep back on both the leading and trailing edges and a progressive wash-out towards the tip. In the early designs vertical rudders were fitted under the wing to provide directional control, but later aircraft employed a form of tip rudder.

The Air Ministry, through the Royal Aircraft Establishment, Farnborough, authorised the installation of a Bristol Cherub engine in the first glider built by Hill (Fig. 7).

Hill joined the staff of Westland Aircraft in 1926 where he was responsible for development which resulted in a further three designs, culminating in 1932 in the Pterodactyl V (Fig. 8).

The Pterodactyl V was an all-metal, two-seater military biplane powered by a Rolls-Royce 600 h.p.

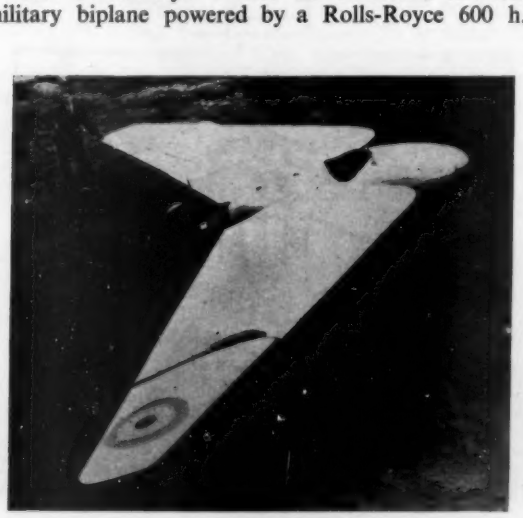


FIGURE 7. Westland Hill Pterodactyl I.

(Courtesy of "Flight")

FIGURE 8. Westland Hill Pterodactyl V.

Goshawk engine. In the course of control development Hill discarded the "floating-tip" controller in favour of normal trailing edge controls. The "floating-tip" controllers, due to inertia effects, had a harmful influence on longitudinal stability and control. The Pterodactyl V was the first tailless aircraft constructed for military use. Handley Page automatic slots were fitted to this aircraft in conjunction with the tailless edge controls to make them more effective at high angles of attack. A great deal of redesign would have been necessary to enable the Pterodactyl V to compete favourably with its contemporaries and so development was discontinued.

The Horten Brothers and the True Flying Wing

As active interest in tailless aircraft waned in England, designers in America and Germany were at work on promising projects. In Germany during 1933 the two Horten brothers built a flying wing glider that subsequently won a prize for originality of design in the 1934 Rhon gliding contest. Like all Horten flying wing aircraft, it had no vertical tail surfaces or rudders; the design was as far as possible, that of a pure flying wing.

In this first Horten glider, the control system consisted of a large, central, trailing edge flap to give elevator control and tip flaps giving normal aileron control; leading edge drag rudders, in the form of spoilers, provided the necessary directional control. By increase of sweepback and aspect ratio and through improvement in control design in the Horten IV they reached the ultimate in flying wing sailplanes. The Horten IV control system incorporated three pairs of flap-like controllers on the outer wings, the outer set of which were ailerons while the inner and middle sets were used as elevators. The movement of the controls was so

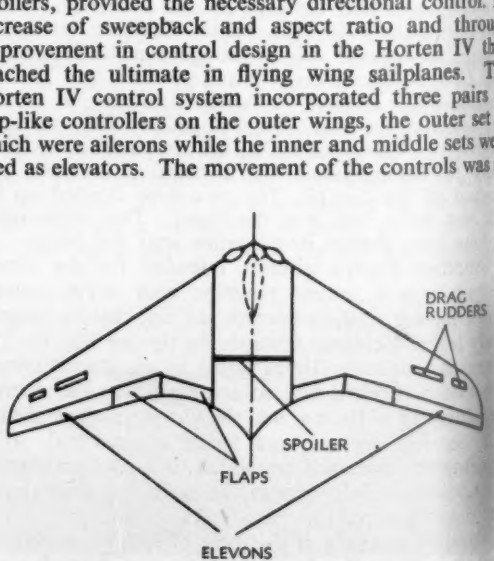
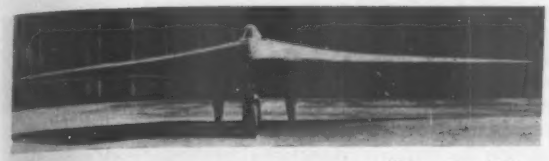


FIGURE 9(*a*). Horten IX Control System.



(*Crown Copyright*)

FIGURE 9(*b*). Horten IX Glider.

integrated that they deflected in the appropriate direction but did so in varying degrees. This arrangement of control helped to maintain effective wash-out and retain stability during manoeuvres. In this design drag rudders, of the spoiler type, were fitted immediately in front of the outer control surface. The design work progressed through two powered flying wings of similar layout to the early gliders, the most noteworthy design being the Horten IX. This project, originally a private venture, called for a jet-powered fighter-bomber capable of speeds in excess of 550 m.p.h. (*see* Figs. 9(*a*) and (*b*)).

The aircraft was essentially a pure swept wing with increased thickness at the centre section to house the pilot and two jet units mounted side-by-side. The powered prototype was preceded by two full size gliders built to test control details and verify design calculations. In the Horten IX longitudinal and lateral control was provided by single stage elevons, while a two-stage drag rudder provided directional control. The drag rudder system was composed of a small, hinged flap situated outboard of the main, large one. The small drag rudder came into operation for high speed control, and for low speed control both sets came into action. A spoiler, for use as a high speed air brake, was situated at about 60 per cent chord distance behind the leading edge and extended over the whole width of the centre section. By the end of the war only two powered examples of the Ho.IX had flown.

Lippisch and the Rocket Propelled Fighter

Lippisch had been occupied during the war years on an advanced tailless design. The move that Lippisch made to the Messerschmitt Company was due to the lack of scope, in the Research Institute, to develop his ideas. Messerschmitt took over the development of the Lippisch-designed research aircraft which then emerged as the Me.163, and the success enjoyed by this project prompted the Luftwaffe to adopt the design as a rocket-powered interceptor (*see* Fig. 10).

By 1944 Squadrons of these aircraft were being formed, their primary task being that of protecting

(*Courtesy of Imperial War Museum*)

FIGURE 10. Messerschmitt Me.163B.

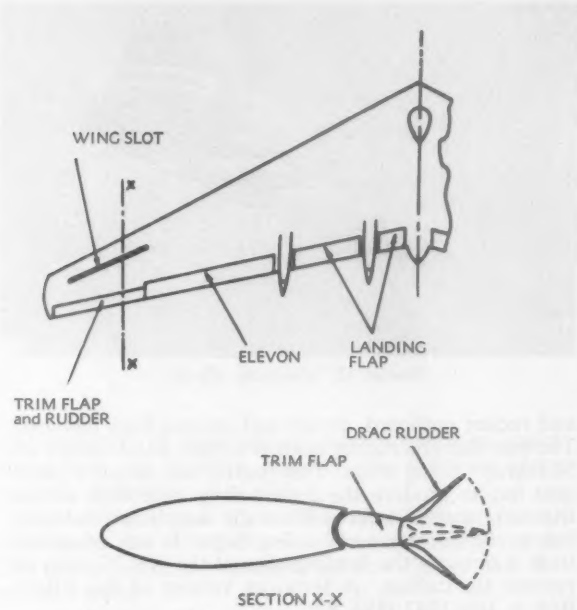


FIGURE 11. Northrop Control System.

certain synthetic fuel plants. In this design normal elevons were used along with small trim flaps inboard, and a fixed slot on the leading edge of the wing delayed stalling. A large fin was provided to maintain good directional control and the aircraft was reported to have docile flight characteristics. Because of the chemical danger from the volatile fuels and the explosion hazard of the temperamental rocket unit, more machines were lost in accident than in combat. Equipped with cannon and air-to-air rockets the Me.163 represented a technical revolution in aerial warfare.

Northrop's Flying Wing

In America the Northrop Aircraft Company was showing active interest in the flying wing layout. John K. Northrop, like Horten, was convinced that great gains, both aerodynamic and structural, could be had from the flying wing design. By 1940 Northrop's piloted scale model of a multi-engine tailless aircraft was flying. This flying model employed sweepback on the leading edge only and had in its design a type of down-swept wing tip similar to that advocated by Dunne in 1911. The elevon control was situated at the trailing edge of these down-swept tips. It was claimed that this type of tip made it possible to obtain almost any desired combinations of lateral and directional stability, without loss of lift. This serves to show how the claims of the tailless aircraft pioneer Dunne were borne out thirty years after he made them.

The next design served to test the aerodynamic configuration for the XB-35 long range bomber. Valuable information on all elements of flying wing design was obtained from this test aircraft.

The XB-35 flew from Northrop Field in June 1946. It had sweepback on both leading and trailing edges and was powered by four piston engines driving pusher airscrews. Its controls (Fig. 11) consisted of trim flap

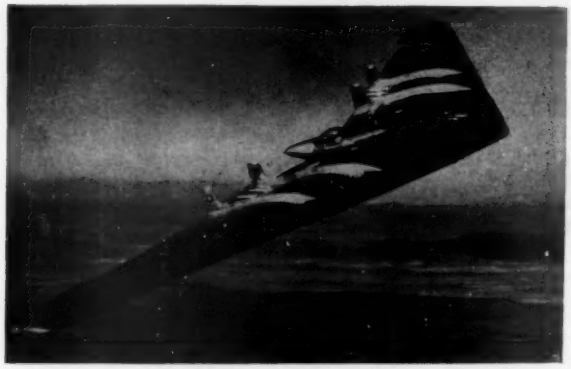


FIGURE 12. Northrop XB-49.

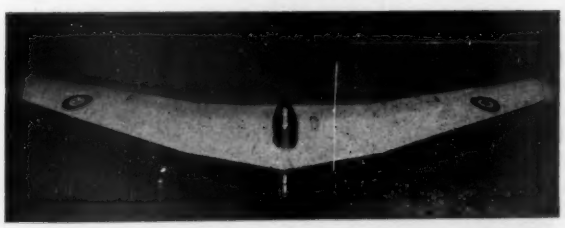
and rudder outboard, elevon and landing flaps inboard. The trim flap and rudder control surface was a feature of Northrop's flying wings. This control was simply a plain split flap to produce the desired drag, combined with a trimming surface to counteract the nose-down moment due to the operation of landing flaps. It was necessary to fit a slot into the leading edge of the XB-35 wing to prevent tip stalling. A turbo-jet version of the XB-35 flew in late 1947 (Fig. 12).

Recent British Progress

During the period when German and American engineers were making progress in the design of all-wing aircraft one or two British firms also became interested in this work. The Handley Page Company, which had been interested in tailless aircraft since 1932 built and flew a twin-engined tailless research aircraft in 1944.

Another contribution came from Armstrong Whitworth. As a preliminary step towards a large, powered flying wing Armstrong Whitworth constructed an all-wing glider (Fig. 13).

This glider, some 53 ft. in span, flew at Reynolds numbers sufficiently great to allow design information to be obtained for a similar project two or three times its size. The most interesting feature of the glider, and subsequent powered aircraft, was the control system. A sketch of the control surfaces is shown in Fig. 13:



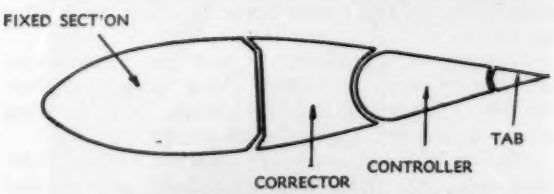


FIGURE 13. Armstrong Whitworth Glider and its control system.

hinged to the fixed part of the wing was the corrector, which in turn carried the controller, to which was hinged an adjustable tab. The corrector was used to counter nose-down pitching moments due to flap operation, as in the Northrop trimming flap, while the controller represented the elevon in its duties. Tip rudders were chosen to improve directional stability and provide a means of counteracting asymmetric thrust due to engine failure in the powered version. Normal Fowler flaps were fitted under the centre section and spoilers were built into the upper and lower surfaces of the wings to improve low speed directional control.

The twin-jet A.W.52 was the result of this glider research. (Fig. 14). The A.W.52 was the first tailless jet aircraft to include boundary layer suction in its control system. This aircraft also embodied in its design a laminar flow wing of a high degree of smoothness, less than one-tenthousandth of an inch irregularity in two inches. These aircraft, although never arousing further official interest, served as research aircraft at the R.A.E. at Farnborough for many years.

At the end of the war in Europe a great deal of information became available from German aeronautical research. An almost direct result of this was the high-speed, long-range bomber project of 1945 by Handley Page, which was a swept wing machine of advanced design. From the control standpoint the design was tailless, having an elevon control system, although a small unconventional tailplane was incorporated in the design solely to control changes of trim due to flap operation or centre of pressure movement at high speeds. This project formed the basis for the Victor design.

In late 1945 the de Havilland Company began design work on a swept wing tailless aircraft, the D.H.108 (Fig. 15). This design embodied a Vampire fuselage and was intended for research into control problems. It was one of these research aircraft that became the first British aeroplane to exceed the speed of sound. The information obtained was of use in subsequent fighter design and in the design of the D.H.106 Comet, than in its early stages.

The work of German aerodynamicists, especially the work of Lippisch in relation to the delta wing, was of great value both here and in America. In America a direct application of the work of Lippisch was the Convair 006 delta wing research aircraft. In England the Avro company, with the Avro 707 series, began research that gave us the Vulcan. So it can be seen that since the

FIGURE 14. Armstrong Whitworth A.W.52.

FIGURE 15. de Havilland D.H.108.

Armstrong Whitworth and Northrop series of flying wings, tailless aircraft in the form of "Deltas" have enjoyed the greatest attention. At the present time there are fully half a dozen tailless delta aircraft in service with the Air Forces of the World, including the Vulcan bomber.

A comparatively recent and interesting tailless aircraft was the Short SB.4 Sherpa (Fig. 16). Although designed primarily to investigate the properties of the aero-isoclinic wing, as a tailless aircraft it made a useful contribution to design development. This particular wing design employed an all-moving wing tip as alternative to the conventional aileron, overcame many of the problems associated with swept wings at high speeds. It is interesting to note that Horten fitted all-moving wing tips to one of his gliders as an alternative form of control.

The latest interest in flying wing design has been shown by Handley Page (Fig. 17). This project is for a fully laminarised, subsonic, passenger air liner to seat 300 passengers and permit the cost of trans-Atlantic air fare to drop to £11 per head. This project is advanced in concept and is a long way from realisation.

Classification

This is a suitable stage at which an attempt can be made to classify the different types of tailless aircraft. It is naturally difficult to draw a dividing line of classification between some types of aircraft because their

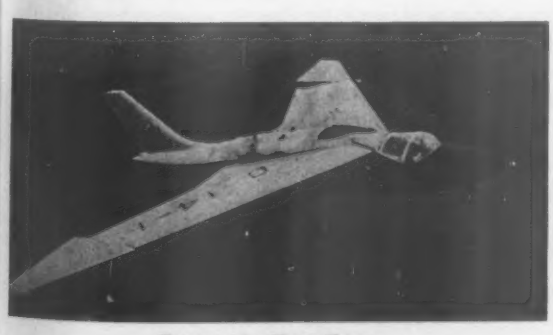


FIGURE 16. Short Sherpa.

FIGURE 17. Handley Page H.P.117.

characteristics fit them perhaps for consideration under more than one heading, however, the following types suggest themselves (Fig. 18).

The Flying Plank Type—This type depends for its stability on the effects of reflex camber of the aerofoil. The most prominent example of this design was the Arnoux series.

Diffuser-Tip Type—This consists of a normally unstable straight-wing plan form fitted with tip attachments to provide stability. In all the diffuser-tip designs a special tip, of one type or another, was fitted to the wing in order to render it stable. Dunne registered a patent on diffuser wing tips, an idea which was incorporated in the Dunne 1911 monoplane.

Delta Type—This is a wing form of triangular shape, having sweepback on the leading edge and a straight trailing edge. The delta shape is the most familiar tailless aircraft shape flying and its development can be traced back to the work of Lippisch.

Zanonia Leaf Type—This is probably the oldest of the tailless aircraft types. The basis of this design is a wing of crescent or kidney shape having wing tips at a negative angle of incidence. The Etrich gliders were good examples of this configuration.

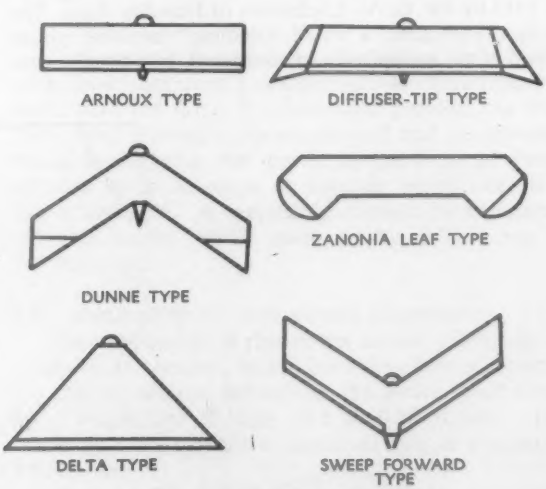


FIGURE 18. Classification of types.

Swept-Back or Dunne Type—An arrowhead plan form with sweepback on both the leading and trailing edges are features of this design. This sweepback is combined with aerodynamic wash-out towards the tip. The swept-back form is the most common basis for development, the work of Dunne, Hill, Horten and Northrop being based on this type.

Swept Forward Type—This class employs a wing with sweep forward on both the leading and trailing edges and aerodynamic wash-in towards the tip. This system, although as stable as the Dunne system, has enjoyed little practical application.

No attempt has been made to classify all the designs that strictly come under the heading "Tailless Aircraft." The introduction of such a diverse collection of types would serve only to make the broad pattern less clear.

Summing Up

There are many advantages, in the structural and aerodynamic sense, to be had from tailless aircraft and consideration must be given to some of the problems facing the designer.

The major tailless aircraft design problem of directional control is of great importance. The problem arises because drag rudders and spoilers suffer from two adverse tendencies; first, to lag in response, and second, to produce effects out of proportion to control movements. The short moment that tip rudders have on an aircraft renders them also ineffective at low speeds.

At low speeds, especially at landing and take-off, a high lift coefficient is desirable. In a normal aircraft any nose-down moment, caused by operation of flaps, is soon balanced by elevator deflection, the elevators being useful because of their long moment arm about the aircraft's centre of gravity. For obvious reasons on a tailless aircraft the balancing effect is small. At moderate sweepback any correcting action of the elevons has little effect. It is paradoxical that increase in sweepback, to improve the effect of the elevons, only renders the flaps less effective. For this reason a compromise has to be accepted and relatively small flaps have to be used, placed in an optimum position.

A reasonable solution to this problem was suggested in 1933 by Dr. G. V. Lachmann of Handley Page. This project embodied a small "floating" aerofoil placed ahead of the mainplane and connected, by way of a small tab, to the main flaps. The setting of the small tab on the "floating" aerofoil dictated the angle at which the aerofoil met the air flow. When the flaps were lowered the "floating" aerofoil moved and produced sufficient lift to counteract the nose-down tendency.

One imaginative engineer suggested a form of retracting tailplane which moved into position for landing and take-off only.

It is evident that full span flaps cannot be used unless some system can provide the necessary correcting moment. A possible solution to the high lift problem would be the use of boundary layer control, thus obviating to a great extent the need for large flap areas and their associated stability problems. This control, in the form of blowing air over the aerofoil or sucking away part of the boundary layer, has immediate application in tailless aircraft design. The Armstrong Whitworth A.W.52 employed boundary layer suction to minimise the swept-wing problem of tip stalling. The Handley Page H.P.117 is planned to have a full boundary layer suction system for the wing surfaces.

Conclusion

In the past the tailless aircraft has suffered setbacks because of the lack of comparable performance with orthodox aircraft. Now, owing to advanced design and control technique, the large flying wing has become a commercial and competitive proposition. The benefits to be had from such a design far outweigh the initial difficulties and it would be a pity if no further British contribution were made to this promising field.

ACKNOWLEDGMENTS

The author wishes to thank the following for assistance with the illustrations: Armstrong Whitworth Aircraft Ltd., Westland Aircraft Ltd., de Havilland Aircraft Co. Ltd., Handley Page Ltd., the Ministry of Aviation, The Imperial War Museum, "Flight," The Royal Aeronautical Society Library, Short Brothers and Harland Ltd. and the Northrop Corporation.

REFERENCES

1 NORTHROP, J. K. (1947). The Development of All-Wing Aircraft, *Journal of The Royal Aeronautical Society*, 1947.

2. LEE, G. H. (1946). The Case for Tailless Aircraft, *Journal of The Royal Aeronautical Society*, 1946.

3. WEYL, A. R. (1944-1945). Tailless Aircraft and Flying Wings, *Aircraft Engineering*, 1944-1945.

Gliding and Man Powered Flight*

by

LORNE WELCH

1. Introduction

As at present envisaged the man powered aircraft will more closely resemble the glider than any other type of flying machine. Because of this it was suggested that a paper on the relationship between gliding and man powered flight might be of value.

The papers which have been read to the Group have dealt with the aerodynamic, physiological and engineering aspects of the problem and they show that a man powered aircraft capable of flight just clear of the ground is a possibility.

Before undertaking the detail design a fourth aspect—pilotage—must be considered. It is in this field that the experience which exists in flying gliders is applicable and should be used.

The paper is divided into three sections. The first deals with the possibility of using man power as an auxiliary engine on a glider.

The second part discusses the possible configuration of a man powered aircraft, and the third and main part of the paper deals with the piloting of such a machine.

2. Application of Man Power to a Glider

2.1. TYPICAL MODERN GLIDER

In view of the current interest in man powered flight it may seem surprising that man power has not been used in gliders, if not to maintain height, at least to prolong the descent.

Gliders have been developed over the past forty years, largely on a trial and error basis, and their main characteristics have now become fairly standardised. There is wide variation in their detail design, but modern high performance gliders are now very similar. Fig. 1 shows a typical example.

A typical single-seat glider of this type has a span of 60 ft., an aspect ratio of 20 and an empty weight of 550 lb., being normally flown at an all-up weight of about 750 lb.

2.2. GLIDER PERFORMANCE

The performance of such an aircraft is most easily studied by a graph giving its rate of descent, or sinking speed, at various flying speeds. (Fig. 2). Typical figures are a sinking speed of 2 ft./sec. at 39 knots and a best gliding ratio of 1 : 36 at 45 knots.

2.3. GLIDER WEIGHTS

An all-up weight of 750 lb. may seem to be high, but a number of successful aircraft are flown at a considerably greater weight. The aircraft has to be strong enough to withstand flying in rough air and landing on rough fields. Because of its clean form and rapid acceleration in a dive it has been found necessary to use a design diving speed well above the normal operating range. Fig. 3 shows a typical flight envelope.

Another reason for the high weight is that apart from the pilot and his parachute the glider carries from 30 to 60 lb. of equipment in the form of instruments, oxygen and radio. The glider's structure is normally fairly simple and, particularly in detail design, is probably not very efficient since little structural testing has been done. To achieve a long life with the minimum of maintenance some weight is sacrificed to robustness. Finally, by aeroplane standards, gliders are cheap; the selling price of a complete aircraft, without instruments, ranges from £2 to £3 per pound of empty weight.

Many efforts have been made to produce smaller and lighter gliders with a good performance and while these aircraft have been reasonably successful in countries with strong thermals they show up badly in weaker conditions. It is clear that with present day methods of design and construction a span of at least 45 ft. is necessary for a satisfactory glider.

2.4. POWER REQUIREMENTS

The power which would have to be applied to a glider to maintain height is most readily assessed by considering its sinking speed and weight; the product of these two giving the number of foot pounds of work lost per second and, this figure divided by 550, giving the horse power. Since a typical glider weighs 750 lb. and has a minimum sinking speed of 2 ft./sec. it will be seen that 2·75 b.h.p. would be needed.

2.5. MAN POWER AVAILABLE

Experiments to determine the power output of a man show that even a trained athlete cannot produce more than 0·5 b.h.p. for prolonged periods, but since there must inevitably be mechanical and aerodynamic losses in applying this power in the form of thrust, whether by an airscrew or flapping wings, not all of this is available. A reasonable estimate for continuous effective output would seem to be 0·37 b.h.p. or 200 ft.lb./sec.

2.6. APPLICATION OF MAN POWER ASSISTANCE

The application of this power to our glider, say by means of an airscrew, would have the effect of reducing the rate of descent throughout the entire speed range by −weight/200 ft./sec.; that is 0·37 ft./sec. This would give the aircraft a minimum rate of descent of 1·63 ft./sec.

Assuming that this power were applied continuously,

*The seventh lecture given to the Man Powered Aircraft Group of the Society—on 20th January 1961.

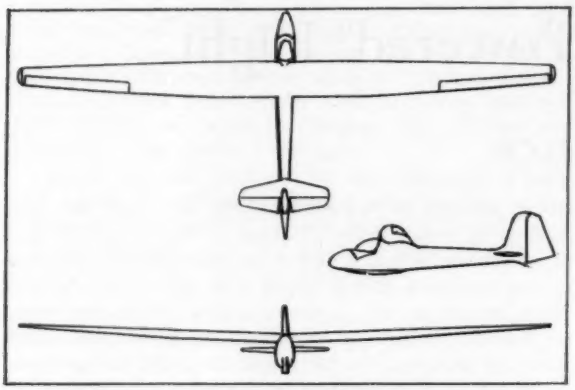


FIGURE 1. Typical modern glider—Skylark III.

the cross country performance would be improved. Fig. 4 shows the average air speeds which a glider can achieve when using isolated thermal upcurrents of different strengths, and the effect of man power. In very weak upcurrents this partially powered aircraft could stay up when an unpowered glider would have to come down, but with more normal strength upcurrents of 4 ft./sec., giving a glider average speed of 23 knots, the performance is only improved to 26 knots. While this improvement is not insignificant, it is doubtful if it could be achieved in practice since no allowance has been made for the increased weight and drag which the installation of man power would inevitably entail. Even more important, the pilot's soaring skill would be much worse. Soaring demands much mental effort, observation and skill, and while exercise may stimulate the mind, the production of half a horse power for one hour, let alone five hours, would result in a very low standard of piloting. Instead of pedalling, a much better flight would be made if the pilot sat calmly back and thought what to do.

It has been suggested by Wilkinson in England and Raspet in the U.S.A. that man power could be more efficiently employed if, instead of driving an airscrew, it was used to drive a fan to give a better degree of boundary layer control; this may be true, but the same objection still applies.

It could be argued that the foregoing analysis is unfair and that man power assistance would appear in a more favourable light if a smaller and lighter aircraft were considered. It seems doubtful however, even if the aircraft could be scaled down to half its weight without worsening its performance, whether the theoretical improvement which man power assistance should give would compensate for the loss of piloting skill.

3. A Man Powered Aircraft

3.1. SIZE AND WEIGHT

The number of possible configurations of a man powered aircraft are many. One simple and probably not very inaccurate way of examining the various possibilities is to take the shape of a typical modern glider as the most effective aerodynamic shape which has been evolved, and consider the effect of varying its size and weight.

Considering our typical glider with a weight of 750 lb. and a sinking speed of 2 ft./sec. it is clear that if the weight could be reduced to one quarter, the sinking speed would be halved. In the same way if the weight remained the same and the span were doubled, that is four times the wing area, the sinking speed would also be halved. If level flight is to be maintained clear of the ground it is apparent, for a single seater, that power cannot exceed about 0·37 h.p., that is 200 ft.lb./sec., and that consequently the product of the total weight and sinking speed in gliding flight cannot exceed this 200 ft.lb./sec.

The results of these crude calculations are shown on Fig. 5 which illustrates some of the possible sizes ranging from an aircraft with a span of 40 ft. and weight of 150 lb. to one of 114 ft. and a weight of 300 lb. Taking a pilot weighing 150 lb. as the minimum capable of producing the required power, it will be seen that there is a choice of structure weights from 50 lb. at 60 ft. span to 125 lb. at 100 ft. span, the cruising speed being 19 knots for the 60 ft. span aircraft and 14 knots for the 100 ft. span. The problem is probably easier to solve, or at any rate least impossible, at some size near that corresponding to the heaviest *empty* wing

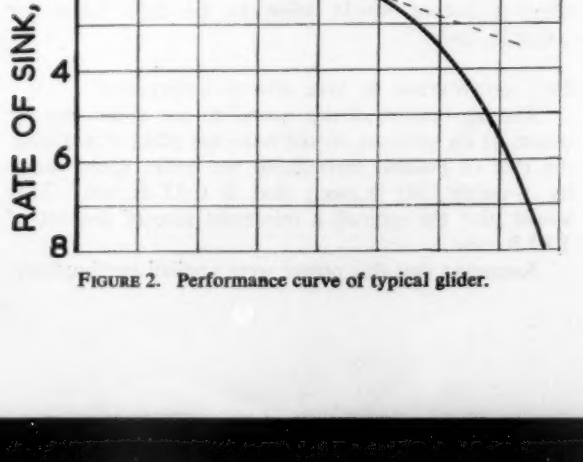


FIGURE 2. Performance curve of typical glider.

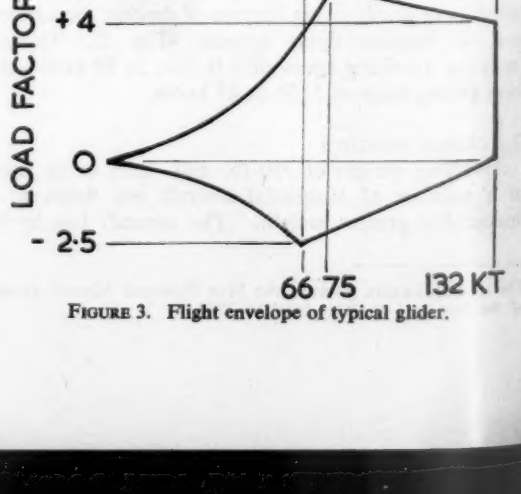


FIGURE 3. Flight envelope of typical glider.

loading or slightly larger than this, as the weight of some parts is independent of size; this suggests a span of about 80 feet. It is possible that with a combination of low load factors, brilliant design and exquisite skill in manufacture such an empty weight could be achieved at the price of extreme flimsyness.

It may be argued that this approach is too crude and that by playing tunes with the aspect ratio, wing section and configuration the equivalent results could be achieved at a greater all-up weight, but against this is the fact that the modern glider is of remarkably fine form and that this approximation is based on the assumption that the same degree of accuracy can be maintained in a structure of a fifth of the weight; any deterioration in shape would demand an even lower weight.

3.2. RATE OF CLIMB

If one succeeded in building this aircraft and getting it into the air clear of the ground, it would be possible to maintain height or even climb if the weight or shape were better than has been assumed. But even if one had 20 per cent surplus energy, and it is doubtful if this could be achieved, the rate of climb would be only 2 in. per second or 10 feet per minute. Such a low rate of climb is much too small to permit safe cross country flight even on the calmest day, since down-currents of much more than 10 feet per minute might be encountered. Consequently it would be most unwise to attempt to fly an aircraft with this very small reserve of power over any high obstacle, in case even a minor down current should be met. To make use of ordinary soaring techniques would be impractical, first because enough height could not be gained before exhaustion set in and second because the aircraft, with its low load factors could not risk encountering any gusts.

Safe flight would therefore only be possible over a flat surface. If this conclusion is accepted there would appear to be little merit in flying at more than a few feet above the ground.

3.3. GROUND EFFECT

The reduction in the induced drag which occurs when an aircraft is flown close to the ground is well known and it seems that success in man powered flight depends on making use of this effect. It is the height of the wing tips above the ground which determines what reduction in the induced drag is obtained. At the speed corresponding to minimum power in flight clear of the ground the induced drag is halved when the wing tips are one tenth of the span above the ground—that is the total drag is reduced to 75 per cent (Fig. 6). An aircraft designed to fly at a very low height could, for the same power output, be made heavier or be more crudely shaped. However, if the aircraft were designed to fly with its wing tips only a couple of feet up there would be no need to use the high aspect ratios which are essential in free air. This would make the whole aircraft much smaller and allow a lighter structure.

The conditions of the Kremer prize, which demand the crossing of the starting and finishing lines at heights of at least 10 feet, could be met by accelerating while

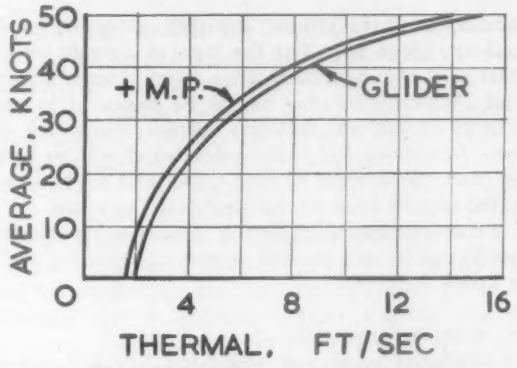


FIGURE 4. The effect on the cross-country performance of applying man power to a glider.

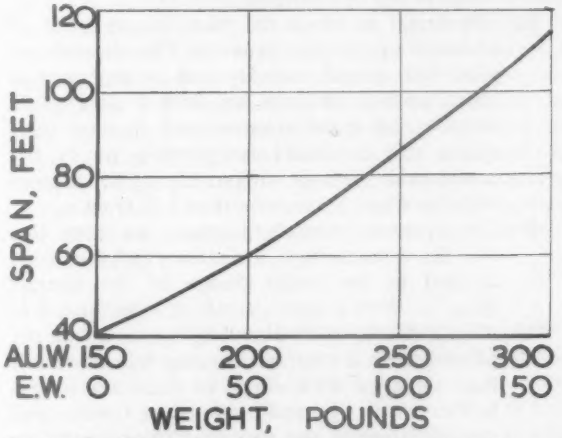


FIGURE 5. Size and weights of possible single-seater man powered aircraft.

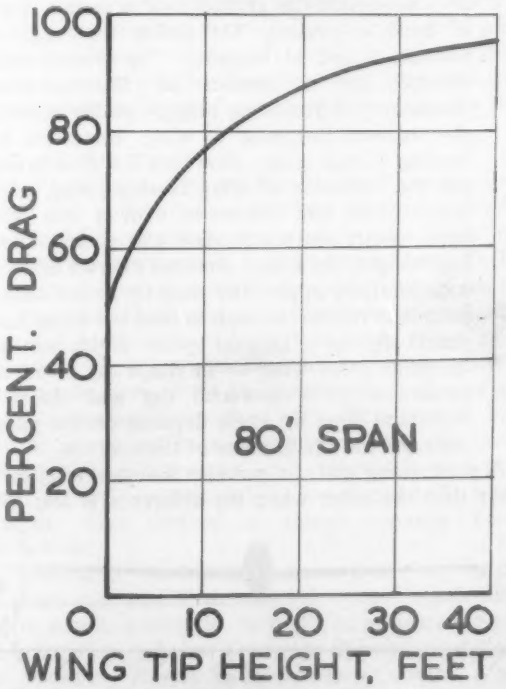


FIGURE 6. The effect of wing tip clearance on total drag.

skimming over the ground and then using the excess speed to zoom up. For the type of aircraft we are considering the minimum drag flying speed will be about 18 knots, but this has to be increased to only 24 knots to provide sufficient surplus energy for the zoom. In making the zoom a headwind will be beneficial since the increase of wind speed with height means that the aircraft need not be accelerated so much.

If one accepts this argument it is essential to select a configuration and control system suitable for really low flying.

3.4. WING TIP HEIGHTS

Considering an aircraft with normal control systems it is apparent that the height of the wing tips above the ground depends on two factors:—

(*a*) The height at which the pilot flies in terms of undercarriage-ground distance. This depends on pilot skill, aircraft stability and elevator control characteristics. In calm air, with a slow speed aircraft with good controls and a good pilot sitting still it should be possible to fly for considerable periods without hitting the ground with the wheel never more than 2 ft. from it.

(*b*) The distance vertically between the wing tips and the undercarriage, a matter which has to be decided in the initial design of the aircraft (Fig. 7). With a light aircraft of large span it is undesirable to allow the wing tips to touch the ground when the aircraft is going fast, as even if they are fitted with wheels or skids any irregularity in the ground will cause swing and possibly damage the aircraft. The aircraft has to be designed, therefore, so that the wing tip does not touch the ground until a certain angle of bank is present. On gliders this angle is between 5 and 11 degrees. The precise angle depends on a number of factors, those demanding a high wing being:—ability to take-off without dropping a wing, clearance for landing in tall crops, clearance for dive brakes and the reduction of wing fuselage drag, while those which are improved with a low wing are:—better rearwards view and reduced fuselage weight. On a man powered aircraft different considerations apply. The wing tip holder should be able to run fast enough to hold the wings level practically up to take-off speed; flights will not be made cross wind or in rough air or in the slipstream of a powerful tug and therefore minimum wing tip angle depends on the pilot's skill and the effectiveness of the ailerons.

A pilot sitting still can perceive that one wing tip is higher than the other when the difference is less than one ft., that is about 1° of bank. Having decided that action is necessary the total angle of bank depends on his skill and the quality of the ailerons, primarily the acceleration in roll. In calm air on a glider when holding off to land only quite small aileron deflections are required, say 1/4 of the total. A man powered aircraft of the same configuration would, by virtue of the slower speed, have considerably worse ailerons, but this would be mitigated to some extent by the reduced rolling moment of inertia. One has the impression when trying to keep the wings level on a glider on take-off or landing that the ailerons lose their effectiveness when one wing tip gets within a foot or so of the ground. How much of this is because of a reduction in lift on the lower wing due to an aerodynamic effect, how much to the wind gradient, and how much to the increased righting moment which is required as the aircraft leans farther and farther over is not known. For these reasons it is difficult to assess the minimum wing tip angle which would be acceptable. An additional factor is the deflection of the wing which will occur when it takes the load; on a glider this is only a few inches, on a man powered aircraft it may be a foot or more. However, as a guess the figure of 5° is suggested; on an 80 ft. span aircraft this means that the wing tips will be 3½ ft. above the undercarriage and therefore in flight about 4½-5 ft. above the ground.

This height could be reduced if an aeroplane type undercarriage were chosen since in a premature touchdown the aircraft would be subjected to a righting force; a lower wing tip angle would therefore be acceptable. Whether this type of undercarriage is worth employing is a matter for debate; it would be heavier and have more drag, but reducing the wing tip height from 5 ft. to 4 ft. reduces the total drag by 5 per cent (Fig. 8).

3.5. CONTROLS

One great unknown is the quality of piloting skill which can be obtained when a man is pedalling hard.

The cyclist's posture appears to be the most attractive from the power output point of view, but the fact that the man has to stabilise himself with alternate up and down loads in each arm makes the design of suitable controls difficult. The alternative position where the pilot is reclining on his back, which was tried on the pre-war designs, offers the advantages of reduced frontal area and, owing to the stabilisation of the upper part of the pilot's body, improved control. But the power output is probably reduced. Which layout is better in a crash or heavy landing is open to debate. If the cyclist position is decided upon it would be preferable to support him in a harness, rather than copy a bicycle and have him sitting on a narrow fence.

The first thing to decide about the controls is whether it is necessary to have the rudder as a separate control or whether it can be combined with the ailerons.

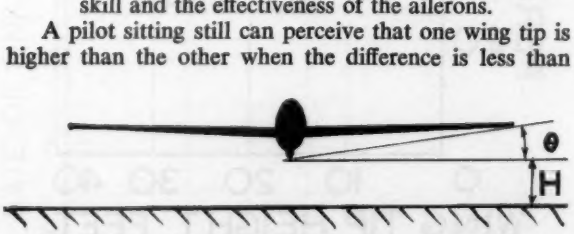


FIGURE 7. Wing tip clearance with glider type undercarriage.

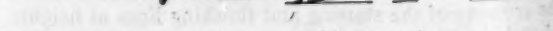


FIGURE 8. Wing tip clearance with wide track undercarriage.

All gliders have a separate rudder control, but the use of this is essential only when flying in rough air, correcting swings on take-off and landing and doing steep turns. It is possible that linked rudder and ailerons would be acceptable if the take-off and landing were made directly into wind and all flights were made in calm air; but inevitably some slip or skid would be present when turning and consequently the drag would be increased. It must be appreciated that the ailerons of a large span aircraft are bad when compared with the most famous aircraft with linked controls—the Ercoupe.

One possible solution would be to link the rudder with the ailerons for normal use, but to have a separate rudder control which would be operated by the knees or feet, when not pedalling, to stop a swing on an abortive take-off and also, during the landing run. Whatever control system is used, it must be extremely sensitive, free from backlash and not subject to involuntary movements when the pilot is pedalling.

3.6. GROUND EFFECT AIRCRAFT

All these considerations lead to the conclusion that, instead of trying to control the aircraft to the necessary degree of accuracy, it would be highly desirable if it could fly by itself at a height above the ground which was dependent only on the speed. I am indebted to Mr. F. G. Irving of Imperial College who has investigated the literature on this matter of a ground cushion aircraft. The conception was patented by Kaario of Finland who claimed that a single aerofoil body could be stable in both pitch and roll if suitably shaped and flown within a few per cent of its chord above the ground. Some further work has been carried out in the U.S.A. and at Imperial College, with promising results.

If such a device could be evolved, one could fly steadily a few inches above the ground; the piloting would be confined to steering in the right direction and the whole aircraft could be very simple and light since there would be no need to make it of high aspect ratio. This principle could also be applied to Hovercraft, where, once under weigh, the sustentation power could be reduced.

One possible configuration for a "skimmer" has been suggested by Cdr. H. C. N. Goodhart (Fig. 9). A man is mounted at each wing tip having his own airscrew. Part, if not all, of the directional control, would be achieved by making one man pedal harder than the other.

This layout, which, at first sight, may seem rather startling, could possibly be applied to a more normal aircraft of higher aspect ratio. It might be possible to eliminate ailerons and have two tailbooms, each with its separate elevator. Each pilot would fly his part of the aircraft at the correct height and thus the two of them would keep the whole aircraft at the right height just above the ground.

FIGURE 9. Front view of " Skimmer " aircraft.

4. Flying the Man Powered Aircraft

The design and construction of the aircraft have so far received the most attention, but the flying of the aircraft is probably just as difficult. It is here that the experience with gliders can probably be of most value, it can certainly show what *not* to do.

4.1. GROUND HANDLING

The first problem is handling the aircraft on the ground. This might seem to be too elementary to be worth considering, but the stalling speed of a man powered aircraft without a pilot will be less than 10 knots; also, it would be frustrating to spend three or four thousand hours of work building the machine if it were blown over the first time that it is pushed out of the hangar to be photographed. The Wright brothers' first aeroplane was blown over on the evening of the day on which they made their first flights and light aircraft have been blown over ever since. The only way to prevent this happening is continuous vigilance and the insistence in having people holding the windward wing tip and the nose and tail. It is easy to say that the aircraft will not be taken out if the wind speed exceeds a certain value, but it is much more difficult to enforce the decision, because the wind has an annoying habit of increasing.

4.2. TRAILER

If the aircraft is built away from the place where it is to be flown it will be almost essential to make a special trailer to transport it when it is de-rigged, otherwise it is bound to get damaged. But even if it is to be flown where it is built, it will probably be worth while making a trailer in which it can be moved fully rigged. A simple, canvas covered, mobile hangar, would take only a few hundred hours to build and would prevent much accidental damage. It would be safer to put the aircraft in its trailer when moving it from one end of the aerodrome to another, rather than push it or tow it.

4.3. FLIGHT TESTING

While it would be possible to start flying the aircraft with man power, there would be a number of disadvantages and it would almost certainly take much longer than if the development is done step by step. To begin with the pilot must not only be a quick witted test pilot, he must also be an athlete—an uncommon combination. He will have to teach himself so many things at once that he will almost certainly make a mistake. Not only has he to learn to fly an aircraft which flies at about half the speed of any fixed-wing aircraft which he has flown before, but he will have to contend with controls of unknown effectiveness, and a control system new to him. If this is not enough he has to pedal like a racing cyclist. This method is almost certainly doomed to failure.

Obviously the first thing to do is to find out if the aircraft flies and if the control system works and to learn how to control it. Secondly to measure the power consumption and thus determine if man powered flight is possible. Thirdly to learn how to control it while pedalling at gradually increasing outputs and then and

only then, to attempt to fly it under man power. The first part of the programme should be undertaken by an experienced pilot, while the actual man powered flights can, after suitable training, be done by someone with more strength than experience. It will be easier to teach an athlete to fly than a pilot to produce half a horsepower.

Ideally the programme should be elaborated by first trying out the control system on an aircraft of proven flying characteristics, but this is probably an unnecessary complication.

4.4. HEIGHT OF TEST FLYING

When testing aeroplanes and gliders, it is the normal practice to carry out all the initial testing high above the ground, the take-off and landings being made at a speed well above the stall. It is only when the slow speed flying characteristics have been fully investigated that the aircraft is flown slowly or even turned near the ground. There are certain advantages in following this practice on a man powered aircraft because matters of stability, trim, control effectiveness and behaviour in turns can be much more easily assessed in steady flight well up in the air, but it is doubtful if it would be wise to do this. To achieve the light weight which is essential for a man powered aircraft, the load factors and design speed must be very low. Shenstone has suggested an ultimate factor of 2·5 and a design speed of 43 knots, and while it would be possible to make many flights within these limitations it would be difficult to guarantee that they would not be exceeded, owing to unexpected gusts or inadvertant steep turns or dives. Being of very clean form, the aircraft would accelerate rapidly in a dive and since the proposed design speed is equivalent to the loss of potential energy of only 80 feet it would not take long to reach its maximum permissible speed.

For these reasons it is suggested that the flight testing should be done in level flight close to the ground. Initially by a series of straight hops and then by flying curved courses.

4.5. METHODS OF LAUNCHING

There are a number of possible methods of launching the aircraft for these early flights:—

1. Bungey.
2. Slope.
3. Car tow.
4. Winch.
5. Aero-tow.
6. Built-in engine.

4.6. BUNGEY LAUNCH

This method of using a rubber shock cord was used in Italy and Germany during the early man powered flight experiments simply because it was then the normal method of launching gliders. Nowadays it would seem to have nothing to recommend it—a steady sustained flight at constant speed is not possible, and the initial acceleration can impose large loads on the aircraft.

4.7. SLOPE

While it might be thought that rolling the aircraft down a gentle slope would be an easy way of getting into the air, in practice it would present insuperable difficulties. There are few slopes with a sufficiently smooth surface and they could only be used when there was no wind or it was from the correct direction. Apart from this, once started the pilot has no means of stopping the flight until he gets to the bottom of the hill, if he swings on take-off he just goes down sideways or hits the hill.

4.8. CAR TOW

This is the simplest method and if both the pilot and car driver are experienced in this system, it should be acceptably safe. It is essential that both vehicles have a quick release, that the rope is fitted with a suitable weak link and that the aircraft is not allowed to climb steeply, or it may be over-stressed or over-speeded. This method has the disadvantage that the propulsive system cannot be tested and it is almost impossible to practice low turns.

4.9. WINCH LAUNCH

Even if a specially light cable is used this system of launching is much less satisfactory than car towing. The winch driver cannot see what is happening nearly so clearly, and consequently speed control is more difficult, also it is more difficult to prevent sudden jerks.

4.10. AERO-TOWING

The only aircraft capable of towing at the low speeds required is a helicopter and, apart from the expense, the method would be unsatisfactory because of the necessity of flying in the wake of the tug.

4.11. BUILT-IN ENGINE

This system appears to have overwhelming advantages. The cost of adapting a light weight petrol engine to drive the aircraft should be comparatively small, the aircraft can be flown over the intended route free from all cables and outside influences. Despite the additional complication it looks as if it would be well worth while arranging for the engine to drive the proper airscrew, rather than have it drive a model propeller.

There are several commercial light weight petrol engines which would be suitable and it should not be difficult to build a reduction gear, torque meter and r.p.m. indicator. These can be either read by the pilot or be of the recording type, or they could be arranged to indicate their readings to an observer travelling in a car behind the aircraft.

4.12. THE PILOT

The pilot must obviously be light in weight, and he must be quick to learn. If the aircraft has a glider type undercarriage it is essential that the pilot has some glider flying experience, otherwise he will not be able to prevent a wing dropping on take-off and landing. In any case experience with gliders is most desirable as the rhythm of the aircraft will be more like a glider than anything else and experience in flying training has shown that, while experienced pilots are not worried by different cockpit layouts, control effectiveness and aircraft attitudes, the thing which is most confusing is a change in rhythm. A man used to flying a large aircraft

is bewildered by the quickness in response of a small machine, and conversely an aeroplane pilot is confused the first time he flies a glider by the slowness of the ailerons, compared to the lightness of the elevator. While it would not be essential to employ a fully trained test pilot, the pilot should have some test flying experience. Pilots who have flown many types of aircraft, may have no skill at analysing the characteristics of an aircraft, even on such an elementary point as the difference between stability and trim.

4.13. INSTRUMENTATION

There is obviously no need to have an altimeter, and while it might be desirable to have an A.S.I. for the initial tests, this could soon be dispensed with since, when flying level, the altitude gives a perfect indication of the speed. Once the optimum has been determined (say tail skid one foot higher than the wheel) the pilot can be shown this attitude when he is sitting in the cockpit and he should know whether he is flying fast or slow by reference to his visual memory of this.

4.14. WING TIP HOLDER

If the aircraft is fitted with a glider type undercarriage, it is necessary to have a man holding the wing tip on take-off. While this might seem to be a simple job, it would be advantageous to have someone who had done it before on gliders, since if he is clumsy the aircraft may swing and be damaged. The technique is to hold the wing tip level, neither pulling back nor pushing forwards until the maximum running speed has been reached and then let go. If the wing tip is held absolutely level, until it is let go, it may drop or rise suddenly and may move through a considerable distance before the pilot can correct it. It is therefore better to let the wing drop or rise a certain amount which ever way it wants to go, before finally releasing it. If this is done, the pilot will have applied at least a partial correction before the wing is free.

4.15. INITIAL HOPS

The initial test flying of a man powered aircraft could comprise the following stages. First the pilot could get used to the control system by wing tip balancing in a light wind. This would enable him to learn how to use the aileron controls and, if the undercarriage were suitable, the elevator controls also. When this had been done, straight hops could be attempted.

The design of the undercarriage will almost certainly demand the use of a smooth hard runway and the wind should either be negligible or the flights should be made into wind. On the first run it will probably be inadvisable to take-off, but merely to test the method of launch and to see if the ailerons and directional controls are satisfactory. Once these have been proved, straight low hops at a few feet above the ground can be attempted. Unless there is absolutely no wind it will be necessary to bring the aircraft back to the end of the runway each time and it is here that a mobile hangar would prove most useful.

If the aircraft had a built-in engine, gentle turns could then be attempted, and when these had been mastered, the power consumption could be measured at various speeds. All these flights would have been made without pedalling; the next stage is to find if the aircraft can be controlled accurately when the pilot is pedalling. To do this, it would be best to fit a simple brake on the pedals and for the pilot to attempt to fly while working against this brake. Only when this had been shown to be satisfactory should man powered flight be attempted.

As it is essential for these early flights to be made in calm air, it will probably be necessary to do them at dawn, since there is a much better chance of obtaining the right conditions then, than there is in the evening.

4.16. TURNS

Since qualification for the Kremer prize will undoubtedly be the goal of early man powered flights it is as well to consider the regulations in detail. The initial rules, dated 1st February 1960 state:—

"4.4. *Course*

4.4.1. The course shall be a figure of eight, embracing two turning points, which shall be not less than half a mile apart.

4.4.2. The machine shall be flown clear of and outside each turning point.

4.4.3. The starting line, which shall also be the finishing line, shall be between the turning points and shall be approximately at right angles to the line joining the turning points.

4.4.4. The height, both at the start and the finish, shall be not less than ten feet above the ground, otherwise there shall be no restriction in height.

4.4.5. The machine shall be in continuous flight over the entire course."

It was presumably intended that the course should follow the shape of Fig. 10 which shows that of an aircraft flying at 18 knots making turns with 10° of bank. The starting line is shown halfway between the turning points, but this is not laid down in the rules. If it is proposed to make turns as steep as this it would be prudent to put the starting line close to the point of initiation of the first turn; the aircraft need then be climbed up only three times instead of four.

There are, however, grave objections to making turns as steep as 10°. When flying slowly close to the ground, steep turns are hazardous since, as the pilot is frightened of digging his lower wing tip into the ground, he tends to do a skidding turn. A glider, and the same applies to a man powered aircraft, is very sensitive to small amounts of slip or skid. An error of only one degree in the angle of bank means that the fuselage must produce a lateral force of about one sixtieth of the weight, or in our case about four pounds. As a device for producing "lift" the fuselage cannot have an L/D which is much more than 8 and consequently an error in bank of one degree may produce as much as half a pound of increased drag; this is more than 5 per cent of the total drag. It is clear therefore that the turns must be made accurately.

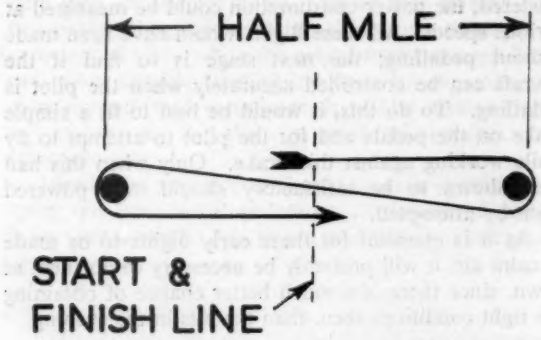


FIGURE 10. Flight course for Kremer prize.

Apart from this, the steeper the turn, the higher must the aircraft be flown above the ground and thus the less will be the reduction of drag due to the ground effect. For a span of 80 ft. each degree of bank implies that the outer wing tip is 1½ ft. above the inner.

For these reasons it is suggested that the turns should be made much more gently, say from 2 to 4 degrees of bank, although this will involve a longer flight time. (Fig 11). However, it is not clear from the Kremer prize rules, whether these courses would be acceptable. This point should be clarified.

For a pilot flying a few feet above the ground it is extremely difficult to judge the turn as it is only too easy to get in too close and make too steep a turn, or alternatively to "run out of aerodrome." It is therefore suggested that before attempting to fly the Kremer course markers should be put out to help the pilot in flying the right line. These could take the form of small brightly coloured balloons spaced at 100 yd. intervals along the course.

4.17. HAZARDS

Because the human body cannot tolerate being dropped more than a few feet—a fact that was demonstrated by Pilcher and Lilienthal sixty years ago—there is an inherent hazard in any form of flying. In learning how to design and fly a man powered aircraft this fact must be respected. When flying the machine under man power in suitable calm conditions the risk is very small indeed; but it must be accepted that the suggested method of developing such an aircraft, by car-towing or with a built-in engine, could easily result in overstressing the airframe or a loss of control. It is therefore to be hoped that those undertaking this flying will be sufficiently knowledgeable, by virtue of their previous aeroplane or glider flying, to understand the risks which they could encounter when attempting to fly a light and flimsy man powered aircraft.

The vital points are:—

For the pilot not to attempt for the first time in a man powered aircraft any type of launch or manoeuvre which he has not practised on a conventional glider or aeroplane.

Not to fly in strong winds or rough air.

Not to let incompetent people "have a go."

To proceed step by step.

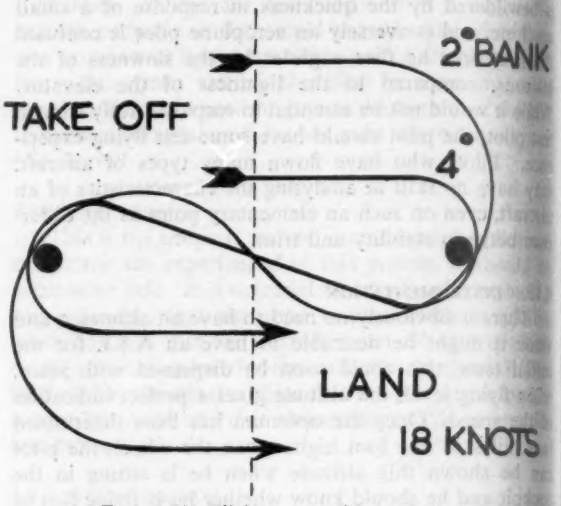


FIGURE 11. Flight course with gentle turns.

5. Conclusions

It is clear that an aircraft theoretically capable of man powered flight close to the ground could be designed and it is probable that it could be built to the desired degree of accuracy within the weight limitation. What is not known is whether a man, pedalling hard, is capable of controlling it with sufficient precision. The evolution of a satisfactory control system will need much development.

A new type of aircraft which, by virtue of its shape, is in stable flight when close to the ground is worth investigating.

The flight testing of a man powered aircraft can best be undertaken either by using glider launching techniques or by the installation of a small engine. In both cases the experience which has been gained in the flight testing of gliders is applicable and should be used.

ACKNOWLEDGMENTS

The author would like to thank Mr. R. Graham who persuaded him to take an interest in this subject, his wife, Ann Welch, who took most of the coloured slides which accompanied the lecture and Mr. F. G. Irving who contributed much useful advice.

(Editor's Note.—In November 1961 the aircraft built by the Southampton Group and by the Hatfield Group made their first man powered flights.)

The Westland range of turbine powered helicopters covers rotary wing aircraft from 5000 lb. to 58000 lb. which are capable of meeting all requirements in all parts of the World.

Advantages of turbine powered helicopters include improved overall operating economy, less noise and vibration and greatly improved performance in high temperatures and at high altitudes.

Westland were among the pioneers in the application of turbine power to the helicopter and already in this class they have in production the Wessex I, Wessex II, Gnome Whirlwind, Belvedere, and the Scout, whilst the development of the 60/65 seat Rotodyne vertical take-off airliner is actively progressing.

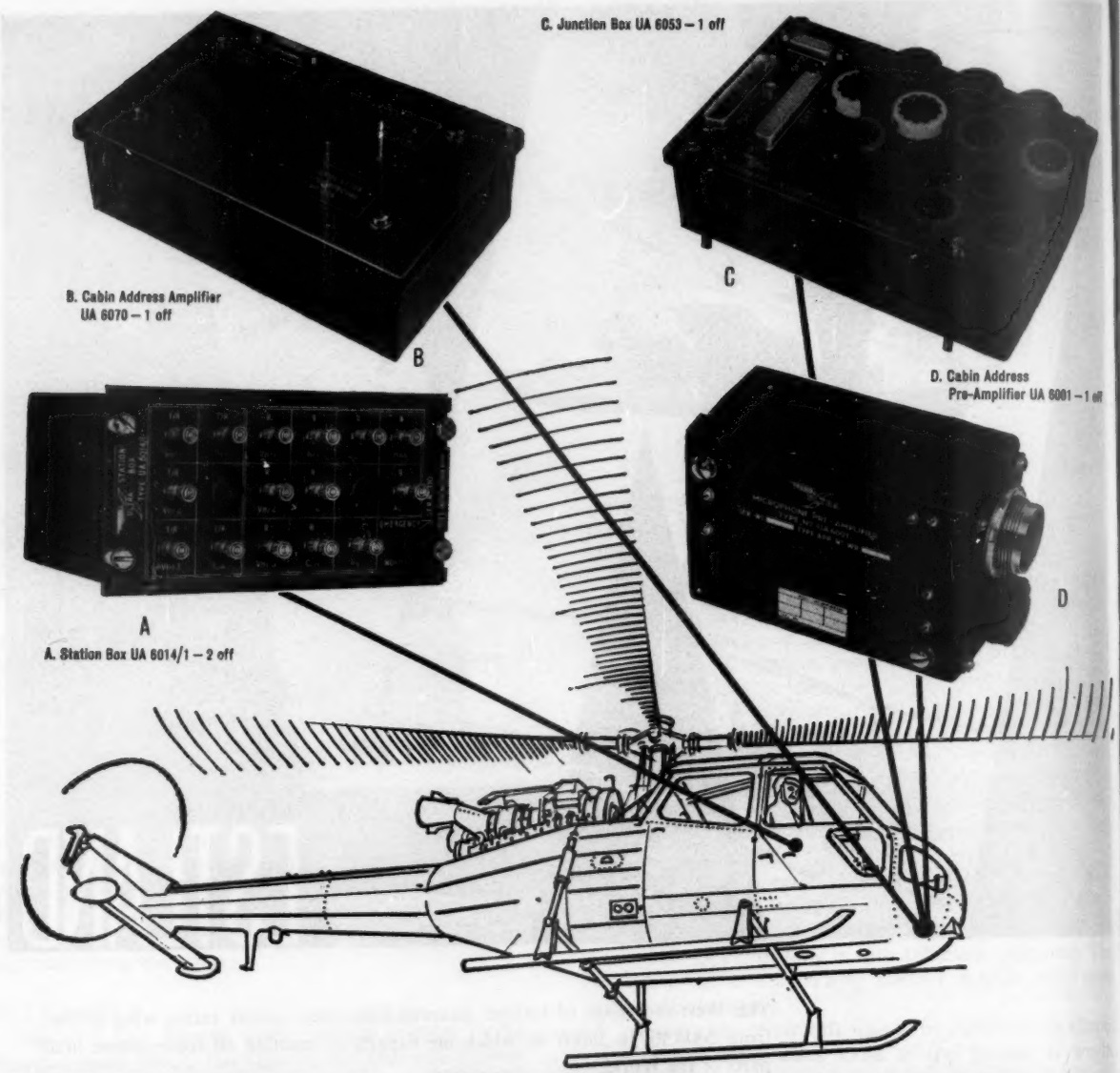
Westland Helicopters are in service with the following:—

Governments of Ceylon, Cuba, Egypt, Iran, Iraq, Kuwait, Hong Kong, France, Thailand, Yugoslavia, Japanese Security Forces, Brazilian Navy, Royal Jordanian Air Force, Ghana Air Force, Royal Navy, British Army, Royal Air Force.

WESTLAND *the great name in HELICOPTERS*

WESTLAND AIRCRAFT LIMITED YEOVIL SOMERSET ENGLAND

Incorporating: Saunders-Roe Division Bristol Helicopter Division Fairey Aviation Division



YOU'LL FIND ULTRA

COMMUNICATION CONTROL, INTERCOM & CABIN ADDRESS

...in the WESTLAND SCOUT*

The versatility of Ultra Type UA60 Communication control and intercom equipment is clearly indicated by the variety of aircraft for which it has been specified, ranging from the Westland Scout helicopter, with seven services, to the Short Bros. and Harland Belfast transport aircraft with thirty-one. And it is equally suitable for American and British radio installations. Audio diffusion amplifiers range from a 2-watt cockpit address type—with integral, but detachable, speaker—to a 60-watt unit developed for use in the Vickers VC10 passenger address system.

** Announcement by courtesy of the Saunders Roe Division of Westland Aircraft Limited*

ULTRA

Please send for brochure

ULTRA ELECTRONICS LIMITED

WESTERN AVENUE · LONDON · W3 · Telephone ACOrn 3434

COMMUNICATIONS · CONTROL AND INSTRUMENTATION · AUTOMATIC BUSINESS EQUIPMENT

The Helicopter, The First of the VTOL Aircraft

BY

RAOUL HAFNER

SUMMARY: A survey is made in retrospect and prospect of the field of VTOL aircraft. The helicopter and the new VTOL aircraft, although historically separated and differing in appearance, belong to the same family of VTOL aircraft. The dominant parameter in this family is the disc loading, giving the two fundamental types of actuator disc—open disc or rotor and buried disc or fan. Noise and vibration criteria are discussed. The rotor is subject to fundamental aerodynamic limitations, which give speed limits for the pure rotor as well as the rotor compounded with a fixed wing. Rotors are subject to scale effects which limit the economic size of helicopters. Engine requirements for helicopters are discussed. There are three basic types of helicopter. Their characteristics, economics and uses are examined.

1. Introduction

It is the object of this paper to present a survey in retrospect and prospect over a wide technical field, which has developed over many years. Space does not permit detailed examination or closely knitted argument on the many themes raised. This is a matter for specialised papers, many of which already exist. More are still needed.

While the word "VTOL" is relatively new, like the aircraft that are associated colloquially with it, the helicopter, the first of the family of VTOL aircraft, has existed as a reality since Breguet's first flight in 1908. Although the old helicopter may appear to have little in common with the modern VTOL aircraft, it belongs nevertheless to the same family. Usually the various species in a large family differ from one another widely in form and size, yet in essence they are the same. It should be borne in mind that there is a time-span of nearly half a century between the old helicopter and the new VTOL aircraft. Moreover, the two have been developed by different generations of investigators who speak, in fact, different technical languages. With the early primitive helicopter elementary lessons were learned which since have almost been forgotten, and now, in the development of the new VTOL aircraft, the same old lessons, in somewhat different form, are being learned again. The autogyro period in the late '20s brought substantial refinement in the aerodynamic theories of the rotor, and also in its design, which gave rise to the renaissance of the helicopter, the first step in its elevation from the crude experimental vehicle to the useful means of transportation. The development since has, by no means, been on a straight course, and has in fact taken rather longer than was originally expected. The helicopter is only just entering the phase of economic utilisation. This has been made possible, among other factors, by the concept of combining rotor and fixed wing and also by the arrival of the ideal engine for the helicopter, the free shaft gas turbine, which are new factors, unforeseen and unforeseeable by the early investigators. Evidently, the metamorphosis of the helicopter throughout these years has been a profound one and, accepting the moral, the author believes that the modern VTOL aircraft, which today is still in the primitive experimental phase, will similarly have to go through an extended period of changes before it emerges in its practical form.

The 10th Lecture given to the Rotorcraft Section of The Society on 5th May 1961.

2. The Two Regimes of Flight in the VTOL Family

VTOL aircraft are essentially hybrids, inasmuch as they are sustained in two heterogeneous regimes of flight, namely (*a*) hovering or vertical flight, where the predominant air flow (induced air flow) is vertical, (*b*) translational flight, where the predominant air flow is horizontal (from translation).

The most efficient means of obtaining dynamic lift in vertical flight is the actuator disc formed by rotating wings. It may be open as in the helicopter, or buried as in fan lift or jet lift aircraft. The basic parameter for the efficiency of this form of lift is the disc loading, which varies widely (from 2 lb./ft.^{2} in the small helicopter to over 2,000 lb./ft^2 in the jet lift aircraft). The most efficient means of obtaining dynamic lift in translational flight, on the other hand, is the fixed wing, and here the basic parameter for efficiency is the span loading. There is no sharp boundary between these two regimes of flight, but there exists an area of transition from one to the other and in this area both means of support function at moderate efficiency.

Directly connected with the problem of lift is that of control in flight, and here too the two regimes of flight produce their distinct problems. Movement in space consists generally of six components, *i.e.* three linear and three angular components. In hovering flight or near-hovering flight (transition) these components can exist independent of one another, so that, theoretically, controls for six degrees of freedom are required (although in practice this is reduced by suitable couplings to four degrees and in some helicopters to five degrees of freedom). In high speed flight, however, the prime consideration is reduction of drag, which leads to the streamlining of the aircraft, and this in turn to the subordination of the linear degrees of

freedom to the three angular degrees of freedom which, simply, means that the aircraft can only fly in the direction into which its nose points.

Moreover, the means of control in the two regimes of flight differ fundamentally. In the hovering regime, control is achieved either directly by changing the speed or the attitude of the rotating wings (vectored lift) or indirectly by non-rotating control surfaces within the air flow generated by these wings. In the high-speed regime, on the other hand, control is obtained best through control surfaces operating in the high-speed ambient air flow.

The problem of stability is also very different in the two regimes of flight. The six independent degrees of freedom of the hovering helicopter, surrounded by a complex pattern of air flow, clearly pose a more difficult problem than the reduced freedom of movement in forward flight in a substantially uniform air flow. In the latter case in a high velocity air flow, stabilisation is obtained in the orthodox and simple manner of the Dart, and angular velocities especially can be damped out easily. On the other hand, lack of adequate damping is one of the outstanding difficulties in the hovering regime. The helicopter pilot in the hovering regime lacks the "feel of the air," and has then surprisingly much in common with the astronaut, whereas in the high speed regime he "feels like a fish in the water."

A problem of control and stability which is peculiar to all VTOL aircraft springs from the fact that, in the low speed regime, the slope of the power demand versus speed curve is steep and *negative*, which with a conventional power supply curve gives an intersection that is unstable. Moreover, in the early primitive helicopters power was controlled by a throttle lever (a relic from the fixed wing aircraft) and rotors, although adjustable like variable pitch propellers, were not readily controllable in collective pitch. Thus the vertical movement of the helicopter was achieved essentially by a constant pitch, variable speed control, through movement of the throttle lever. This method of control involving the inertia of rotor and engine was sluggish and required, to be effective, a substantial surplus of power to meet transient conditions. As the early helicopter had scarcely sufficient power to hover, the paradoxical situation arose of there being perhaps just sufficient power for take-off but insufficient for a safe controlled landing.

With the introduction of the collective pitch control as a primary flying control the control loop changed fundamentally to one by variable pitch, constant rotor speed, which was not detrimentally affected by rotor and engine inertia; on the contrary, the kinetic energy stored in these parts became beneficial in rapid control manoeuvres. In order to match power supply with power demand, a linkage was provided between throttle lever and collective pitch control (pitch-throttle correlation linkage). Alternatively, the transmission system was fitted with a constant speed governor. With the introduction of two and more engines this problem becomes now, of course, more complex and fail safe techniques will have to be used to ensure satisfactory operation of this vital control.

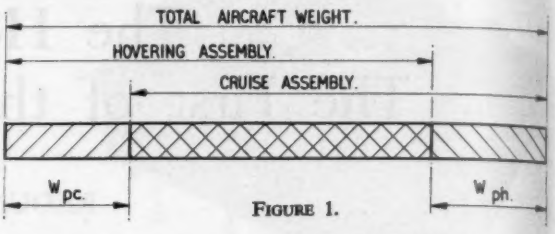


FIGURE 1.

One imagines the jet and fan-lift aircraft to be even more sensitive to this aspect of control than the helicopter with its relatively low disc loading.

The two regimes of flight differ also fundamentally with regard to power demand. In hovering flight the predominant component is induced power, and the power of parasitic drag is nil. At high speed, on the other hand, the induced power is negligible and the parasitic power dominant.

From the above it is evident that there is a fundamental difference between the two regimes of flight. The VTOL aircraft must, therefore, be fitted with means adaptable to suit both regimes of flight, or such means must be supplied in two versions, one for each regime of flight. Therefore parasitic weight will generally be carried in both regimes. Consider W, the total weight of the aircraft (*see* Fig. 1). Consider also W_{ph}, the parasitic weight in the hovering regime, and W_{pc}, the parasitic weight in the cruising regime, then the total parasitic weight factor will be

$$F_{pt} = \frac{W_{ph} + W_{pc}}{W}$$

Clearly an ideal condition is achieved when the parasitic weight penalties in either regime are nil. In this case, $F_{pt}=0$. On the other hand, the worst arrangement is obtained when the hybrid VTOL aircraft is made up of two complete aircraft, one for the hovering regime and the other for the cruising regime. In this case $W_{ph}+W_{pc}=W$, and $F_{pt}=1$. The designer will endeavour to hold the parasitic weight factor at a minimum, which is achieved by keeping the parasitic weights in the two flight regimes as low as possible. There are, of course, conflicting requirements and a compromise has to be made which, if successful, produces the "balanced VTOL aircraft." The following example may serve to illustrate this point. A compound helicopter, *i.e.* a helicopter comprising rotor and a small fixed wing, may require a considerable amount of power for take-off because of high induced losses due to a small rotor disc. Consequently a heavy power-plant is needed. The power demand at cruising speed may be rather less than that at hovering, and consequently the parasitic weight penalty in the cruising regime would be the excessive weight of the unnecessarily large power-plant. This aircraft is badly balanced. Improvement could be achieved by increasing the auxiliary wing, which by unloading the rotor would permit higher forward speed and thus permit better utilisation in the cruising regime of the available power. Alternatively an improved balance could be achieved by increasing the rotor disc which would decrease the induced power in the hovering regime, and with it the installed horse power.

3. The Disc Loading Parameter

The parameter responsible, more than any other, for the wide variety of form in the VTOL family, is the loading of the actuator disc. It can vary from 2 lb./ft.² in the light helicopter to over 2,000 lb./ft.² in the jet lift aircraft. In the former case a large mass flow of air is involved in the production of lift, and induced velocity and power are small. In the latter case the necessary rate of change of momentum is obtained by a small mass flow of air acquiring a high induced velocity and the power needed is high, so high in fact that the air employed in the production of power is identical with that involved in the production of lift. The by-pass ratio of zero governs thus the upper limit of disc loading. In Fig. 2 induced velocity and power per lb. thrust are shown as a function of disc loading, and according to the size of actuator disc, VTOL aircraft can be divided into two main categories: —

(*a*) those with large open discs (all types of helicopter);

(*b*) those with small buried discs (all types of fan lift and jet lift aircraft).

Actuator discs can be buried in a VTOL aircraft only if they are sufficiently small to come within the silhouette of the aircraft. Fig. 2 gives the silhouette of such an aircraft with a typical wing loading of 100 lb. per sq. ft. The total actuator disc area is about one fifth of the wing area. It is evident that larger buried actuator discs cannot effectively be installed. This makes the minimum disc loading for buried actuator discs about 500 lb. per sq. ft. Thus the two categories of VTOL aircraft can be defined further as follows: —

(*a*) those with open actuator discs with disc loadings from about 2 lb. per sq. ft. to about 500 lb. per sq. ft.;

(*b*) those with buried actuator discs with disc loadings from about 500 lb. per sq. ft. to about 2,000 lb. per sq. ft.

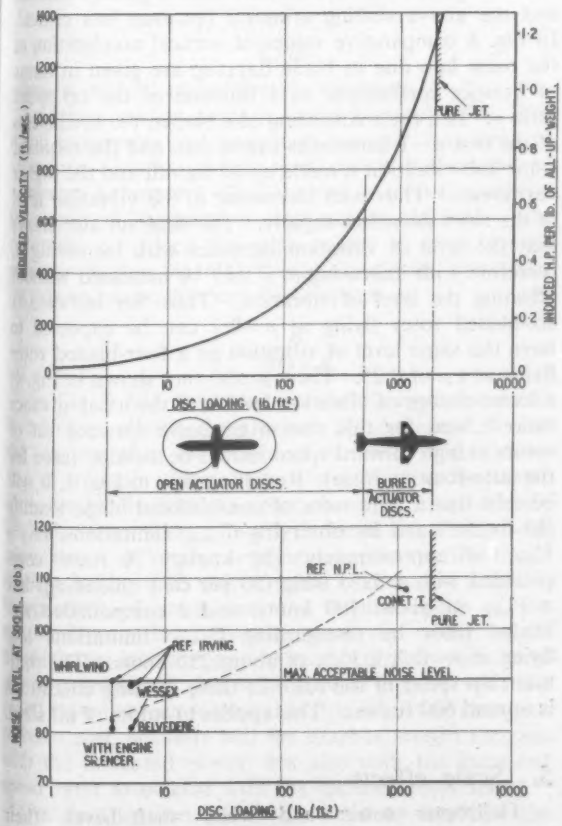


FIGURE 2.

With powered lift are necessarily connected vibration and—its audible part—noise. These arise mainly from two sources: —

1. The power producer and the transmission.
2. The actuator disc and associated elements.

In the jet lift engine these merge into one.

Vibration or noise may either exhibit a dominant frequency or they may be a blend of a great number of frequencies (white noise). The latter comes mainly from vorticity in the air generated in the passage through engine and actuator disc, whereas the former is due mainly to cyclic phenomena in the rotating wings, turbine blades and gears.

The mechanism of white noise and vibration is complex, and the generally accepted technique of dealing with it is of breaking the vibratory pattern up into portions of small mass, and thereby increasing frequency beyond the threshold of perception.

Noise and vibration of dominant frequencies can be controlled by changing such frequencies. Thus the level of vibration in a helicopter can be decreased effectively by increasing the number of blades in the rotor(s). There is, however, a distinct limit to such increase, because, as soon as the blade frequency (which is rotor frequency × number of blades) reaches the audible range of frequencies, vibration becomes noise. This is the case of fast turning tail rotors which, while rarely presenting vibratory problems, frequently are the cause of serious noise. For this reason, the tandem rotor configuration can be made very quiet.

Noise increases with power, engine speed and air speed. In Fig. 2 the overall noise level in decibels produced at a distance of 400 ft. from a medium-sized aircraft, supported by actuator discs of various disc loadings, is shown.[4] Also given there is a threshold of acceptable noise for city centre operation. This line intersects the curve at a point corresponding to approximately 25 lb./ft.² disc loading. Therefore, only aircraft with disc loadings below this value are suitable for city centre operation. It also shows the very important fact that only open actuator discs can be permitted into cities.

4. Aerodynamic Limitations of the Rotor

The rotor may be defined as a set of rotating wings sweeping an open actuator disc and producing dynamic lift. In hovering or axial flight the aerodynamic conditions are simple. The flow pattern is symmetrical about the rotor axis. The lift produced by the wings is steady. The aerodynamic conditions of a rotating wing in this condition are as follows: —

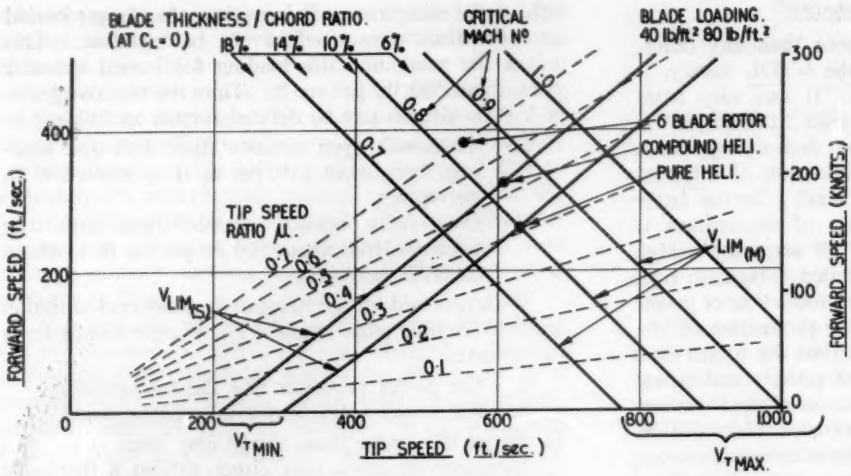


FIGURE 3.

(*a*) A given lift may be produced at an angle of attack corresponding to $C_{L\,max.}$ of the aerofoil, which will be achieved at a minimum tip speed $V_{T\,min.}$ (*see* Fig. 3). Below this tip speed limit the rotating wing will stall. The minimum tip speed depends on the value of $C_{L\,max.}$ and on the blade loading. The higher the $C_{L\,max.}$ and the lower the blade loading, the lower $V_{T\,min.}$

(*b*) The same lift may be produced at a small angle of attack at a tip speed which corresponds to the critical Mach number of the aerofoil. Above this tip speed limit $V_{T\,max.}$ transonic phenomena arise. The speed range between these limits is known as the hovering tip speed range. The rotating wing can produce steady lift at any tip speed V_T within these limits.

These aerodynamic conditions change materially in forward flight (forward speed V_F). In this case the advancing blade tip experiences a speed of V_T+V_F, whereas on the retreating side of the rotor the resultant speed is V_T-V_F. In the fore and aft sectors of the rotor the air flow is oblique. To maintain a tolerably constant lift during rotation, the lift coefficient must be varied cyclically, *i.e.* it must be lower on the advancing side and higher on the retreating side than in the hovering case.

On the advancing side the problem is one of critical Mach number and, therefore, with increasing forward speed the maximum tip speed must be reduced, *i.e.*

$$V_T = V_{T\,max.} - V_F$$

This gives a limit line $V_{LIM\,(M)}$ which is 45° inclined to the base line.

On the retreating side of the rotor, the problem is one of blade stall and, therefore, with increasing forward speed the minimum tip speed must be increased. Although here the relationship between V_T and V_F is somewhat more complicated, $V_{LIM\,(S)}$ is also inclined to the base line.[1]

With increasing forward speed the tip speed range of the rotor clearly decreases until at maximum forward speed it is shrunk to nil. Thus the aerodynamic limitations of a rotor are given by a triangle, with the hovering tip speed range at its base and the V_{LIM} lines at its sides and the maximum forward speed as its height.

What are the means to increase this height? Clearly increase of the base line will increase height. $V_{LIM\,(M)}$ can be moved to the right by increasing the critical Mach number of the blade tip, and blade sections of low t/c are advantageous.[1] On the other side, $V_{LIM\,(S)}$ can be moved to the left by increasing $C_{L\,max.}$ and reducing blade loading. The performance gained from an increase in $C_{L\,max.}$ is limited but a substantial gain is possible by reduction of blade loading. This is achieved not so much by increasing the area of the rotating wing, which is already optimised for the hovering condition, but preferably by employing an auxiliary fixed wing which, with increasing forward speed, will progressively unload the rotor and so reduce blade loading. The shift of $V_{LIM\,(S)}$ by a 50 per cent reduction of blade loading is shown in Fig. 3. When the rotor is made up of a large number of blades, the combined effect of the fluctuating lift of the individual blades is greatly reduced and the above stalling criterion becomes less critical. In Fig. 4 comparative values of vertical acceleration at the rotor hub due to blade flapping are given in terms of Fourier coefficients, as a function of the tip speed ratio μ. In a rotor consisting of n blades, the coefficients of the first $n-1$ harmonics cancel out, and the resultant rotor hub vibration is made up of the nth and the higher harmonics. Thus with increasing n, the vibration level of the rotor decreases rapidly. The diagram also shows that the level of vibration increases with increasing μ, therefore with increasing n, μ may be increased without affecting the level of vibration. Thus, for instance, a six-bladed rotor flying at $\mu=0{\cdot}7$ can be expected to have the same level of vibration as a four-bladed rotor flying at a μ of 0·25. There is also (not shown in Fig. 4) a lesser change of vibration level with the axial advance ratio λ, and for this reason excessive forward tilt of rotors at high forward speed should be avoided (case for the auto-rotating rotor). Reverting now to Fig. 3, it will be seen that a pure rotor of conventional blade loading (80 lb./ft.²) and by observing $C_{L\,max.}$ limitations, has a $V_{max.}$ of approximately 150 knots. A rotor compounded with a fixed wing (50 per cent unloading) has a $V_{max.}$ of about 190 knots, and a compounded six-bladed rotor by disregarding $C_{L\,max.}$ limitations and flying at $\mu=0{\cdot}7$, a V_{max} of about 230 knots. The optimum tip speed of the rotor in these limiting conditions is around 600 ft./sec. This applies to rotors of all sizes.

5. Scale effects

Helicopter rotors and—when shaft-driven—their transmissions, are subject to scale effects which

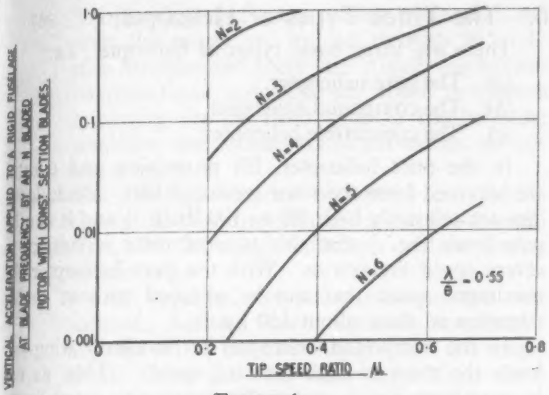


FIGURE 4.

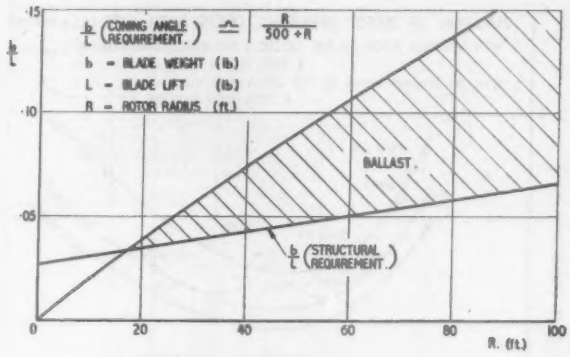


FIGURE 5.

fundamentally influence the economics of the aircraft. Since the radical advances made in the autogyro period, rotor blades do not carry lift loads in bending like fixed wings, but are articulated at the hub to flap freely and assume during rotation a position (at a coning angle β_0 above the flat rotor disc) of equilibrium between lift forces acting at right angles to the disc and centrifugal forces acting parallel to the disc. It has been shown[2] that there exists a relation between coning angle β_0, blade weight b and blade lift L, rotor tip speed V_T and rotor radius R, which can be expressed by the equation

$$\frac{b}{L} = \frac{1}{\dfrac{k_c^2 V_T^2 \beta_0 + 1}{k_1 g R}}$$

where k_c and k_1 are integration constants.

A large coning angle is quite acceptable for slow flying helicopters such as cranes; however, it is a source of serious vibration at high speed and in fast compound transport helicopters β_0 is indeed a critical quantity. In speeds of 200 knots it must not exceed 0·05. The optimum tip speed for such rotors is given in the previous Section as 600 ft./sec., and with this value the above expression can be rewritten as

$$\frac{b}{L} \simeq \frac{R}{500+R}$$

In Fig. 5 b/L is plotted against the rotor radius R. It increases almost directly with R. A second line in the diagram gives the weight of the blade in consideration of strength. Thus, up to about 17 ft. radius, rotor blade weight is equal to about three per cent of blade lift. But from there onwards it increases directly with rotor size. A similar argument applies to the transmission in the shaft driven rotor. As the tip speed is independent of rotor size, the angular speed of the rotor will vary inversely with rotor size. The weight of gearboxes increases approximately directly with horse power transmitted, but also almost directly with the speed ratio between rotor and engine. Thus with increase of rotor size, not only will the gearbox weight increase with the increased power, but also with the increased speed ratio associated with the reduced rotor speed.[3]

An investigation has been made to establish the influence of these scale effects on a family of high-speed, compound tandem rotor helicopters. They are four-engined, with an engine-out capability. They also carry blind flying and navigational equipment, as well as furnishing items of a standard demanded in modern air liners. The result is given in Fig. 6, showing disposable load against all-up-weight for three families of helicopters, *i.e.*

(*a*) powered with 2,500 h.p.;
(*b*) powered with 5,000 h.p.;
(*c*) powered with 10,000 h.p.

In each family the rotor size is varied systematically and with it such components as are affected by the change in rotor size, or by the change in the all-up-weight of the aircraft, the remainder staying unchanged. Taking, for instance, the curve for 5,000 h.p. it will be seen that it emerges from the base line at one end at a minimum rotor diameter with a disc loading of 29 lb./ft.^{2} The disposable load here is zero. This is because of the high induced power due to the high disc loading. A maximum of disposable load is achieved at the optimum disc loading for this power of 3·2 lb./ft.^{2} Beyond this point the disposable load decreases, reaching zero value again at a very low disc loading of 18 lb./ft.^{2} In this case the high weight of the rotor and the transmission, due to the scale effects mentioned, is responsible

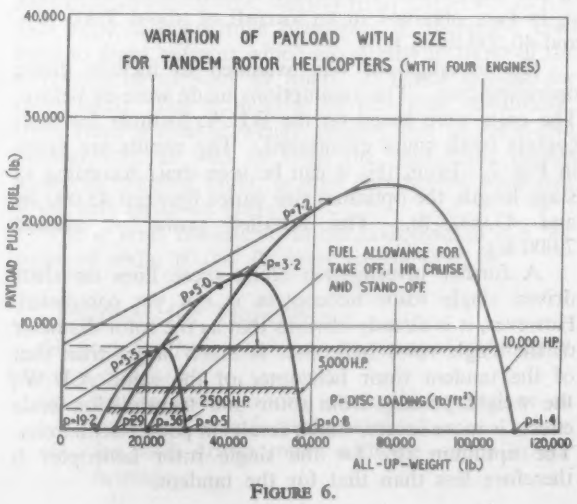


FIGURE 6.

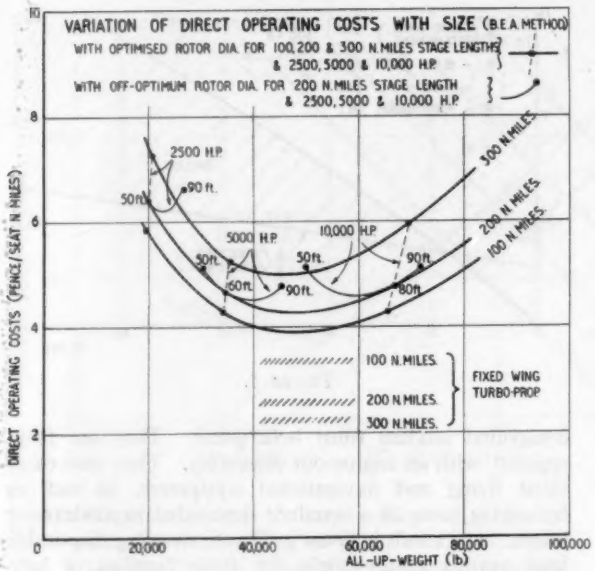


FIGURE 7.

for the vanishing disposable load. Similar observations can be made with the families of helicopters represented by the two other curves for 2,500 h.p. and 10,000 h.p. Considering now the optima for these curves, namely the points of maximum ratio of payload to all-up-weight (which is the point on the curves common with a tangent to it; this tangent intersects the vertical axis at a height which represents a fuel load corresponding to a typical short-haul flight of one hour). On traversing from low to high power, it will be seen that the all-up-weight increases and *so does the optimum disc loading*. Thus in a major change of power from 2,500 h.p. to 10,000 h.p. there is only a small change in rotor diameter. The diagram also shows that, of the three tangents, the steepest (*i.e.* that of maximum percentage payload) is the one for the 5,000 h.p. curve, the other two being flatter. The maximum percentage payload in the high speed compound tandem rotor helicopter is, in fact, obtained in an aircraft of about 5,000 h.p. and 40,000 lb. A.U.W.

The investigation was extended to include direct operating cost. The assumptions made were as before. The costs were based on the B.E.A. formula for helicopters (with small deviations). The results are given in Fig. 7. From this it can be seen that, according to stage length, the optimum size varies between 43,000 lb. and 47,000 lb. The installed power is around 7,000 h.p.

A further investigation along these lines on shaft driven single rotor helicopters is not yet completed. However, it is already obvious that as the rotor diameter of the single rotor helicopter is much larger than that of the tandem rotor helicopter of the same A.U.W., the weight penalty from rotor and transmission scale effects is more severe, which results in poorer economics. The optimum size for the single rotor helicopter is therefore less than that for the tandem.

6. The Three Types of Helicopter

There are three basic types of helicopter, *i.e.*

(*a*) The pure helicopter.
(*b*) The compound helicopter.
(*c*) The convertible helicopter.

In the pure helicopter, lift propulsion and control are obtained from the rotor (vectored lift). Blade loadings are relatively high (80 to 100 lb./ft.^{2}) and it can be seen from Fig. 3 that this type of rotor is subject to severe speed limitations. With the pure helicopter the maximum speed that can be attained without undue vibration is, thus, about 150 knots.

In the compound helicopter an auxiliary wing offloads the rotor at high forward speeds. This, as can be seen from Fig. 3, materially widens the speed limits. By introducing a large number of blades, a further speed gain is possible, bringing the speed limit in the neighbourhood of 230 knots. I regard this the practical speed limit for the compound helicopter.

In the low speed range, where the auxiliary fixed wing is ineffective, the compound helicopter functions like a pure helicopter. In the high speed range, however, where rotor lift is substantially reduced, control and propulsion by the rotor(s) are also reduced and these deficiencies may have to be made good by other means.

Control in roll can readily be augmented by small ailerons in the auxiliary fixed wing.

Control in yaw can be improved in the tandem configuration by a rudder in the fin structure which carries the rear rotor. In the single main rotor configuration the tail rotor too may require to be compounded with a fin and rudder.

Augmentation of fore and aft control is achieved in the single rotor configuration by a tailplane and elevator. There is no such control problem in the tandem rotor configuration, where large pitching moments are obtained, independently of total rotor lift, through differential lift of the two rotors.

Deficiencies in rotor propulsion can be made good by separate propelling means, such as propellers driven from the transmission system (Rotodyne), or by separate engines or jet propulsion from the exhaust of the main engines (Type 194), or from separate engines.

The convertible helicopter also contains the basic elements of the compound helicopter, *i.e.* rotor and fixed wing. However, in this case a complete conversion is made from the flight regime of the rotating wing to that of the fixed wing or vice versa. Various forms of conversion are possible.

(*a*) During transition from one regime to the other the whole aircraft is rotated through approximately 90°. Thus in the hovering flight regime the rotors are horizontal supplying the sole lift for support and the fixed wing is vertical giving zero force, whereas in high speed flight the fixed wing being horizontal supplies the sole lift and the rotor, being vertical, provides the propelling force. This type of helicopter[3] is moderately simple, but has obvious disadvantages in take-off and landing.

(*b*) The fuselage and wing remain horizontal and only the rotors are rotated through 90°. In this arrangement there are major mechanical complications and also the rotor downwash impinging on the fixed wing in the hovering condition and during transition causes serious buffeting.

(*c*) The fuselage remains horizontal and rotors, engines and transmission and wings are rotated. Here the following conditions pertain during transition: —

At hovering, the rotor provides the sole support. Induced flow is vertically downwards and the lift of the fixed wing which is vertical is nil. Then the wing rotor assembly is tilted slightly forward and the aircraft gathers forward speed. The resultant speed vector at the wing is the vector sum of forward speed and induced speed from rotor thrust. Thus the wing lies at a positive angle of attack in relation to ambient air flow, and produces a lift. At the same time, the rotor experiences an axial as well as an in-plane component from this forward speed, which gives rise to the aerodynamic dissymetry in the flow pattern familiar from the other types of helicopter. Half way through the transition the dissymetry in the rotor as well as the angle of attack of the fixed wing reaches critical conditions. The former reaches a tip speed ratio of the order of $\mu = 0{\cdot}2$, which necessitates the use of articulated rotor blades, and in fact that whole "know how" of orthodox helicopter engineering, and the latter attains angles of attack of about 20° which calls for special super-circulation devices such as leading edge slots, blowing, and so on, in order to avoid wing stall. Beyond this point conditions improve again, the flow of the rotor becomes axial and the angle of attack of the fixed wing reverts to modest values.

(*d*) Fuselage remains horizontal. Rotors and wing are rotated separately. At first the wing is rotated faster than the rotor and later vice versa, so that both complete the 90° rotation simultaneously. The object of this arrangement is to avoid the high angle of attack of the wing during the middle part of the transition, and the associated complications in scheme (*c*).

I was concerned in a study of a convertible helicopter a few years ago, and scheme (*c*) was selected[8]. The following salient points arose from this investigation.

The wing, although carrying the total aircraft weight at high speed, need only be designed for such speed and is therefore somewhat smaller than that of an ordinary aeroplane, which must also meet take-off and landing requirements. The rotor, which during take-off and landing carries the total aircraft weight, is dimensioned accordingly. In forward flight the rotor acts only as a propeller and as such produces only a fraction of the thrust needed in the hovering flight regime. Blade area is thus excessive in this case, causing unnecessarily high profile power, a parasitic feature in the forward flight regime. This can be compensated to some extent by seeking substantial cruising heights, where air density is materially reduced. At such height, however, cruising speeds can be attained which compare with those of the turboprop aeroplane, namely from 350 to 400 m.p.h. This type of convertible helicopter is, therefore, confined to flight patterns which are similar to those of the turboprop or turbojet air liners. It is not suitable for short haul. The economies of this type of aircraft, apart from a modest weight penalty due to rotor and transmission, as well as from the high rotor profile power in cruising flight, is also comparable with that of the turboprop air liner.

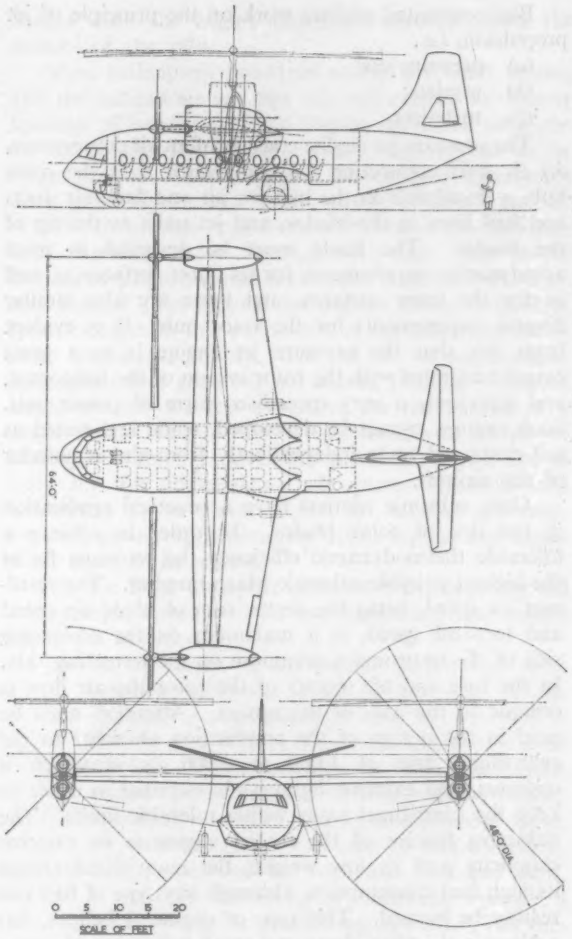


FIGURE 8. Bristol 199 Tilt Wing Aircraft.

The aircraft considered in the investigation is a 50-seater of about 60,000 lb. gross weight (Fig. 8).

7. Engines for Helicopters

Engines for helicopters can be grouped principally into two categories: —

(*a*) for tip driven rotors, where the engine, or at least part of it, is blade mounted;

(*b*) for shaft driven rotors with the engine in the fuselage.

Blade-mounted engines work on the principle of jet propulsion, *i.e.*,

(*a*) pressure jets;
(*b*) ramjets;
(*c*) turbojets.

The pressure jet engine consists of an air compressor, an air duct connecting the compressor with the rotor hub, a distributor in the hub for air and fuel, air ducts and fuel lines in the blades, and jet units at the tip of the blades. The blade must be designed to meet aerodynamic requirements for its outer surfaces as well as for the inner surfaces, and there are also similar diverse requirements for the rotor hub. It is evident from this that the pressure jet engine is to a great extent integrated with the rotor system of the helicopter, and represents a very specialised form of power unit. Such engines cannot be developed, made and tested as self-contained units independently from the remainder of the aircraft.

Only subsonic ramjets have a practical application at the tips of rotor blades. In order to achieve a tolerable thermodynamic efficiency the jet must fly at the highest possible subsonic Mach number. The resultant air speed, being the vector sum of blade tip speed and forward speed, is a maximum on the advancing side of the rotor and a minimum on the retreating side. In the fore and aft sectors of the rotor the air flow is oblique to the axis of the ramjet. Attention must be paid in the design of the combustion chamber to the centrifugal field of 1,000 to 2,000 *g*'s in which it operates, and extreme lightness is essential in order to keep the centrifugal loads within tolerable limits. The attractive feature of the ramjet engine is its extreme simplicity and its low weight; the main disadvantage its high fuel consumption, although any type of fuel can readily be burned. This type of engine, I believe, has a place in the ultra-cheap and small helicopter, the two-seater for the Army as well as in certain civil uses. It could also be used with advantage in the very large flying crane.

Proposals and investigations on blade-mounted turbojets have been made[7] both in this country and in the U.S.A. Much of what was said of the ramjet applies also to the turbojet, except that in this case, mainly because of the higher compression ratio, there is a much lower fuel consumption. The turbojet, however, even in its simplest form is mechanically much more complicated than the ramjet, and is therefore much more sensitive to high centrifugal forces. However, if this rather serious difficulty could be overcome then there would undoubtedly exist a field of application for the blade-mounted turbojet, particularly in the larger heavy load-lifting rotors (flying crane).

Engines for shaft driven rotors are of conventional configuration, inasmuch as they are mounted in the airframe, and provide power via a shaft. The arrival of the light gas turbine has greatly advanced the performance of the helicopter, which is more sensitive to weight penalties than the fixed wing aircraft. Nevertheless, some of the highly developed piston engines in the U.S.A. are still very attractive to the manufacturer of small helicopters, mainly because of their cheapness. However, one of the major penalties with the piston engine is the need for a clutch in the transmission to the rotor.

The fixed shaft turbine is used in a helicopter exactly like a piston engine, *i.e.* it is connected to the rotor by a clutch. As the rotor is operating substantially at constant speed the fixed shaft turbine is a constant speed engine, and changes in torque are obtained only through changes of the combustion temperature, the mass flow remaining substantially the same. Such an engine is capable of quick changes of power which is desirable in the helicopter, especially during take-off and landing. However, as the operating speed of the turbine has to be set at a level that can be sustained continuously, there is inherent in this type of engine a power limitation which prevents the achievement of high power even for very short periods, which is particularly needed in power units for multi-engined helicopters. The single engine helicopter is not affected by such requirement, and there one may well use fixed shaft turbines, which are somewhat simpler than free shaft turbines.

The free shaft turbine has two fundamental advantages in the helicopter over the fixed shaft turbine:—

(*a*) It has a built-in fluid drive which obviates the need for a clutch.
(*b*) The freedom of the gas generator permits, through variation of combustion temperature as well as mass flow, a wide range of power at substantially constant free turbine speed. This is important for multi-engined helicopters.

Against these advantages of the free turbine there is one major shortcoming. As a change in power can only be effected by a change in gas generator speed, inertia is involved and rapid changes in power cannot readily be achieved.

Compressors and fuel metering units are more sophisticated, critical flight idling and ground idling speeds must be observed. It may be possible, however, by judicious selection of operating speeds, of free turbine and gas generator, and by the fitting of a free-wheel between these two units, to combine some of the good features of the types of gas turbine (*i.e.* operation in the free turbine mode within the normal power range and in the fixed shaft turbine mode for idling).

Engine ratings for helicopter turbines have been the subject of many discussions in recent years, both in this country and the U.S.A. The helicopter, taking off and landing vertically, needs a system of engine ratings which is fundamentally different from that for the engine of the fixed wing aircraft, which takes off along a runway.

In the single-engined helicopter the maximum of power is demanded from the engine during V.T. and V.L. and also during any manoeuvre involving hovering. Flight duration is relatively short and therefore the ratio of time in high-powered flight to overall time is rather higher than that of take-off time to overall time in the fixed wing aircraft. Thus the power level of the orthodox take-off rating is too high for this purpose in the single-engined helicopter, and a new helicopter rating has been established which lies roughly five per cent below the five-minute fixed wing take-off rating.

In the twin- and multi-engined helicopter the problem of engine ratings is more complicated. Here one is mainly concerned with the large transport helicopter, in particular with achieving in operations from confined areas a high standard of safety together with a maximum of economy. Such helicopters must, of course, be able to fly with one power unit inoperative. The power required in a helicopter is a minimum at moderate cruising speed, and by providing sufficient power to permit a modest rate of climb with one engine inoperative at this speed, safe operation in *en route* flight is ensured. In order to meet the case of an engine failure at speeds less than the above a certain flying procedure must be adopted.[2] Take-off in confined areas accordingly is made in a substantially vertical direction up to a so-called decision point. Should an engine failure occur before decision point is reached, then, there being insufficient power to maintain height, a vertical return is made to the take-off point. Once, however, decision point is reached and an engine fails, the aircraft is accelerated smartly until cruising speed is obtained. In this process, energy of height is converted into energy of speed, and the decision point must therefore be placed at a height sufficient to allow for this unavoidable height loss as well as for an adequate safety margin to clear obstacles below. In both cases, *i.e.* rejected take-off as well as continued take-off, there is a need for the maximum of power that the engine can safely give, and for this purpose a special helicopter turbine rating—the 2½ minute rating—has been introduced. It lies about 10 per cent above the 5-minute take-off rating of the fixed wing aircraft.

In the helicopter the collective pitch of the rotor blade, which governs the vertical performance of the aircraft, is directly under the control of the pilot. This control movement affects the power demanded by the rotor, and engine controls must therefore link up with the collective pitch control movements. In many simple single-engined layouts there is in fact a mechanical "link up" between collective pitch control and throttle control by what is known as the pitch-throttle correlation linkage. Control movements in the helicopter can be quite rapid and a quick response of the engine to changing power demands is therefore essential. In multi-engine configurations, moreover, it is necessary to obtain, after the engine failure, an increase in the power of the remaining operative engines, adequate to make good the loss. But even this is not sufficient as the reaction time of the pilot is generally too long to permit effective recovery action in this critical period. Therefore, automatic devices must be installed which instantaneously make good the power loss after an engine failure. As the maintenance of constant rotor speed is also a desideratum, such devices usually take the form of a constant speed governor. The governor must be designed to sense the speed of the rotor system. It must also be designed to fail safe. (At least it should be duplicated together with a discriminator to detect and eliminate the faulty signal.) It must control simultaneously the throttles of all engines. The rotor speed governor differs thus fundamentally from the propeller speed governor, which varies the pitch of the propeller blades while the engine throttle is directly under the control of the pilot.

Most helicopters produced so far are shaft driven, and the indications are that this will remain so. Power loadings of helicopters have slightly decreased since the arrival of the gas turbine. They also appear to be insensitive to all-up-weight. Twin-engine helicopters have generally a little more power installed per lb. A.U.W. than single-engine ones, because of the performance requirement for the engine-out case. The power loading of single-engined helicopters is about 8 lb./h.p., and that of twin-engined helicopters about 6 lb./h.p. (power datum in this connection is the helicopter maximum continuous power). The A.U.W. of single-engine helicopters does generally not exceed 13,000 lb. because larger aircraft are too expensive for the hazard of a single engine failure. This weight then, with the power loading of 8 lb./h.p., gives the maximum engine size of 1,600 h.p. for single-engine helicopters. Medium-sized helicopters up to about 22,000 lb. A.U.W. are twin-engined, giving approximately 1,800 h.p. as the maximum size for the engine.

For the large transport helicopter, the four-engined arrangement appears to be the optimum. The reason for this is as follows: —

(*a*) In the event of an engine failure the twin-engined helicopter loses 50 per cent of the installed power, whereas only 25 per cent is lost in the four-engined arrangement. Thus the four-engined arrangement achieves the same critical performance with less installed power.

(*b*) The ability to ferry with one engine inoperative, *i.e.* take-off, cruise and land in this condition, without payload but with fuel load and crew, is rapidly becoming a standard operator's requirement for fixed wing aircraft. The airworthiness authorities consider in such case the possibility of a failure of a second engine, at any time during flight, in particular during take-off, and demand an adequate performance with two engines inoperative. This leads to the three-engined configuration as the theoretical minimum, and to the four-engined configuration as the practical answer to the problem. The civil transport helicopter, which will operate from confined roof sites in the centres of cities, will need to meet this ferrying requirement even more than the fixed wing aircraft, and it will therefore almost certainly be powered by four engines.

In the Section on Scale Effect of the Rotor it is shown that the optimum size of this type of helicopter varies according to criteria from about 32,000 lb. to 47,000 lb. A.U.W. The power loading for these aircraft is approximately 7 lb./h.p., which, with four engines, gives maximum engine sizes between 1,200 and 1,700 h.p.

To say that specific weight and specific fuel consumption should be as low as possible is a platitude. It is, however, important to note that the helicopter is essentially a means for short haul, and therefore specific weight is more important than specific fuel consumption. While there are operating requirements for very short

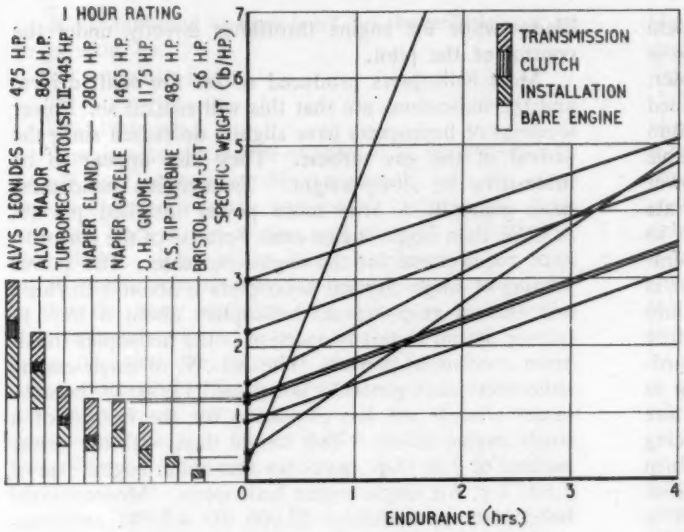


FIGURE 9.

duration (Army observation helicopter, a half hour) as well as for relatively long duration (anti-submarine warfare helicopter, up to four hours), the typical journey time of the civil helicopter is one hour. In Fig. 9 specific weight as well as fuel are given against flying time for various forms of engine. The free shaft turbine, with its built-in clutch, has a good all-round performance. The fixed shaft turbine, although as an engine is somewhat lighter than the free shaft turbine, needs a clutch in the transmission, and this makes the installed weight higher than that of the free shaft turbine. The ramjet engine, being extremely light in installation but heavy in fuel consumption, is most suited for very short duration. The piston engine is altogether too heavy, and is only of interest because of its low specific cost. It is, in fact, the turbine, in particular the free shaft turbine, that brought the performance of the helicopter to an economic level.

8. Economics of the Helicopter

The economics of the helicopter can be demonstrated in many ways. Two have been selected.

(*a*) A comparison of various types of helicopter and other VTOL aircraft.

(*b*) An evaluation of direct operating costs of a family of high-speed transport helicopters of the compound tandem rotor type.

The comparison covers a range of VTOL aircraft varying widely in all-up-weight, cruising speed and operating conditions (*see* Table 1).[3, 5, 6]

The comparison is based on a well-established assumption that the product of block speed and percentage payload is a fair yardstick for economics. Block speed, being the mean speed attained between take-off and landing, is sensitive to terminal acceleration, deceleration, climb, and so on. These can be combined into a terminal time loss Δt. Slow aircraft flying low have a small terminal time loss, whereas fast aircraft attaining their full cruising speed V_c only at great height have a large loss. It is assumed that

$$\Delta t \text{ (minutes)} = 0{\cdot}5 + \frac{V_c^2 \text{ (knots)}}{16{,}000}$$

Δt is shown in column four of Table 1. (No allowance is made for terminal delays due to traffic control.)

For the evaluation of the percentage payload, all those parts in the first instance were considered, which are essential for support and control of the aircraft in both regimes of flight, *i.e.* lifting engines, propulsion engines, ducts and cowlings, wings, rotors, controls, stabilising equipment, and so on. To this weight was added the fuel for five minutes of hovering. These

TABLE I

	A.U.W. lb.	*Cruising speed V_c kts.*	*Terminal time loss Δt mins.*	*Type of Aircraft*
1. *Bristol VTOL Study	over 100,000	400	10·5	Jet lift VTOL aircraft
2. *Type 199	60,000	360	8·6	Convertible helicopter, side by side rotors. Shaft driven by four turbines.
3. *Type 194	33,800	200	3·0	Compound tandem rotor helicopter. Shaft driven by four turbines.
4. Belvedere	18,500	120	1·4	Pure tandem rotor helicopter. Shaft driven by two turbines.
5. Wessex	12,600	113	1·3	Pure single rotor helicopter. Shaft driven by single turbine.
6. Fairey Ultra Light	1,800	75	0·9	Pure single rotor helicopter. Blade mounted pressure jets.
7. *Type 190	1,200	75	0·9	Pure single rotor helicopter. Blade mounted ramjets.

weights (Group A) are given as a percentage of take-off weight in the lower blocks of Fig. 10. It can be seen that these items are lightest in the simple ramjet helicopter (18 per cent) and become progressively heavier with increasing complexity, as well as increasing specific power installed. (VTOL fan lift 51 per cent.)

As to the remainder of the aircraft (Group B), *i.e.* airframe, undercarriage, furnishings, navigational equipment, communications, passenger service items, crew, and so on, the various types differ widely, because of differing requirements and also perhaps because these items have not been considered in sufficient detail in some of the cases, especially those marked with an asterisk in Table 1, which represent only relatively crude feasibility studies. They are shown as a percentage of take-off weight in the upper blocks of Fig. 10.

It is the purpose of this comparison, rather than giving *actual* performance, to show the *relative* performance of the various configurations. For this reason a generalised allowance is made for the items in Group B, which are common to all aircraft and therefore do not constitute a variable in this comparison.

Assumption B_1: 25 per cent of A.U.W.

Assumption B_2: 30 per cent of A.U.W.

which is shown by the two lines B_1 and B_2 in Fig. 10.

The last item is the fuel used for a given distance. It is calculated from the hourly fuel consumption and the cruising speed. This is indicated by the inclined lines on the right in Fig. 10. The distance between these lines and B_1 or B_2 represents the percentage payload for any given stage length.

The product of block speed and percentage payload is shown in Fig. 11 as a function of stage length. This product is very sensitive to the allowance made for Group B items, especially in the case of fast aircraft or those with a high value for Group A items. It is also evident that the helicopter has the clear advantage in short haul and the fan- or jet-lift aircraft will compete only when it flies fast *and* far. The convertible helicopter shows off well over the medium range of stage lengths.

The information in Fig. 10 together with the cruising speeds quoted in Table 1 have been obtained from brochures, and the like, on the various projects, and Fig. 11 results from this information. It should be borne in mind that, whereas some of these projects are aircraft in production, others are, at best, feasibility studies. The curves in Fig. 11 are, therefore, where appropriate, subject to "factors of optimism."

The object in the evaluation of D.O.C.'s for a family of compound tandem rotor helicopters is to establish absolute values for comparison with those of conventional aircraft, and also to determine the effect of aircraft size on D.O.C.'s.

The family of helicopters discussed in Section 5 and shown in Fig. 6 was examined. The conventional assumptions and methods of computation[8] were made with minor exceptions (for maintenance purposes transmissions were considered part of the engine). The results of the examination are given in Fig. 7. They represent the direct operating cost of optimised helicopters of various A.U.W. They are given for stage lengths of 100, 200 and 300 nautical miles. There are also shown for the 200 mile stage length D.O.C.'s for "off-optima designs." The lowest D.O.C.'s are obtained with aircraft of about 47,000 lb. A.U.W. Values of under 4d. per seat nautical mile are reached for the 100 mile stage length. D.O.C.'s of modern turboprop air liners are also given for comparison.

Similarly, the direct operating costs of the convertible helicopter shown in Fig. 8 have been obtained. They are

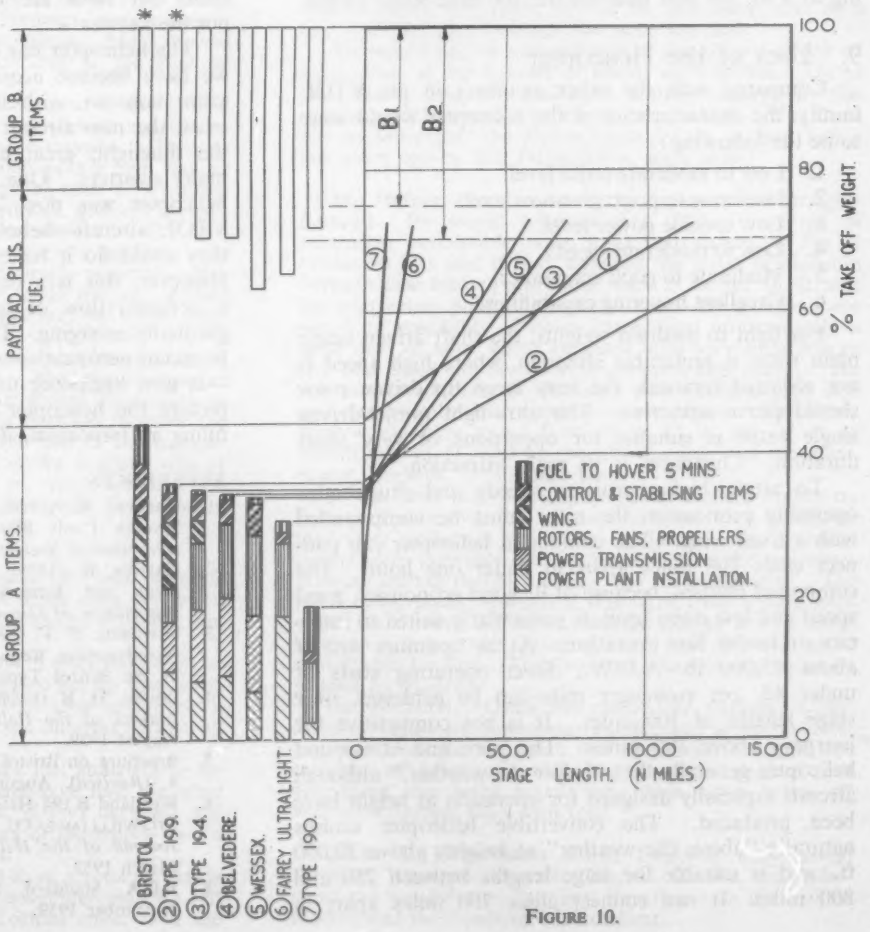


FIGURE 10.

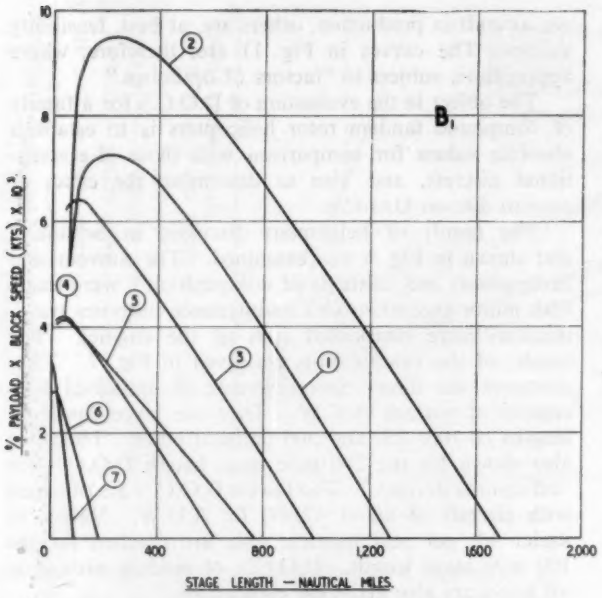
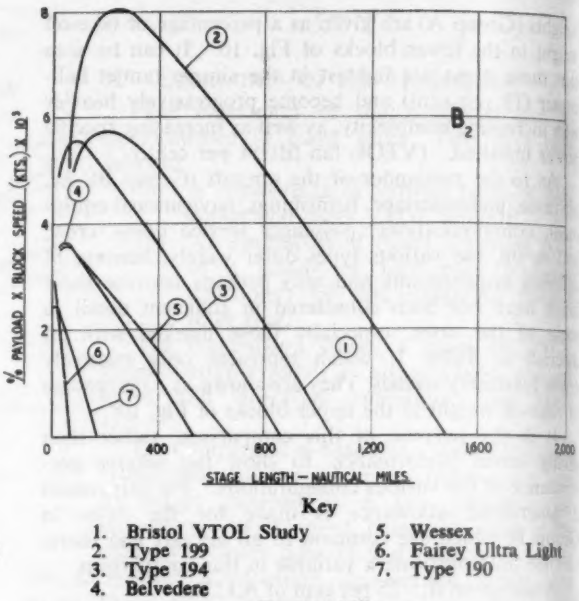


FIGURE 11(*a*).



Key

1. Bristol VTOL Study
2. Type 199
3. Type 194
4. Belvedere
5. Wessex
6. Fairey Ultra Light
7. Type 190

FIGURE 11(*b*).

3·5d. per seat mile for the 500 mile stage length, increasing to 5·5d. per seat mile for the 100 mile stage length.

9. Uses of the Helicopter

Compared with the other members in the VTOL family, the characteristics of the helicopter would seem to be the following:

1. Low to moderate noise level.
2. Moderate to poor vibration level.
3. Low specific power level.
4. Low to moderate speeds.
5. Moderate to good economics.
6. Excellent hovering capabilities.

For light to medium weights, the shaft driven single main rotor is preferable although, where high speed is not required (cranes), the very large tip driven rotor should prove attractive. The ultra-light ramjet-driven single rotor is suitable for operations of very short duration. Cheapness is its main attraction.

To attain higher cruising speeds and thus better operating economics, the rotor must be compounded with a fixed wing. The compound helicopter can connect cities 200 miles apart in under one hour. The compound tandem, because of its good economics, good speed and low noise level, is particularly suited to intercity or feeder line operation. At its optimum size of about 45,000 lb. A.U.W., direct operating costs of under 4d. per passenger mile can be achieved, over stage lengths of 100 miles. It is not competitive for journeys above 300 miles. The pure and compound helicopter generally flies "below the weather," although aircraft especially designed for operation at height have been produced. The convertible helicopter cruises naturally "above the weather" at heights above 20,000 ft., and is suitable for stage lengths between 250 and 800 miles. It can connect cities 700 miles apart in under two hours. If cruising speeds higher than 350 knots per hour are required, then the helicopter is not the answer.

The helicopter has been with us for many years and we have become acquainted with its advantages and, even more so, with its shortcomings. In late years, when the new aircraft of the VTOL family came into the limelight, great expectations were entertained in many quarters. One heard it said, in fact, that the helicopter was now "on its way out." These new VTOL aircraft—behold—could do the hovering trick, they could do it better and do much more besides it. However, this is a one-sided, incomplete view and in a constant flow of new evidence the *whole* truth is gradually emerging. The picture of a great development in recent aeronautics—the family of the VTOL aircraft—is now beginning to assume perspective, and in this picture the helicopter can be seen in its many shapes filling an important, if not dominant, part.

REFERENCES

1. HAFNER, R. (1954). The Domain of the Helicopter. Seventh Louis Blèriot Lecture, *Journal of the Royal Aeronautical Society*, October 1954.
2. HAFNER, R. (1955). Bristol Type 173, Design, Development and Experiences. *Journal of the Helicopter Association of Great Britain*. August 1955.
3. SUTHERBY, P. F. (1956). Bristol Aircraft Ltd. Helicopter Aerodynamics Report No. 83. Initial Performance Study of the Bristol Type 199 Convertiplane. December 1956.
4. IRVING, H. B. (1959). Helicopter Noise Suppression. *The Journal of the Helicopter Association of Great Britain*. August 1959.
5. Brochure on Bristol Type 192 (Series 2). SEB. 113. Issue 4. (*Revised*). August 1959.
6. Westland B.194 Helicopter. Brochure No. 221. Nov. 1960.
7. FITZWILLLIAMS, O. L. L. (1952). The Giant Helicopter. *Journal of the Helicopter Association of Great Britain*. March 1952.
8. B.E.A. Standard Method of estimating "A" costs. November 1959.

DISCUSSION

Dr. G. S. Hislop (Special Director and Chief Engineer, Fairey Division, Westland Aircraft, *Fellow*): Two years ago the helicopter was regarded as "passé" but, since the recent conferences in the U.S.A., at Farnborough and in Paris on VTOL transports, its merits were now being looked at by those outside the helicopter field with considerably less prejudice. In the VTOL transport field there would not be anything to push aside the helicopter and its variants for some time to come. He wondered if Mr. Hafner were going to show the serious implications of high specific fuel consumptions of some of the direct-lifting VTOL jets they had seen, and particularly the effect on fuel reserves in transport operations. In inter-city operations there must be allowance for fuel for one abortive landing and with this the case for these VTOL machines therefore took a severe knock.

Mr. Hafner said that the ram-jet was attractive for short range operations. Quite a few had been built but they did not seem to have "cottoned on"; he wondered why. Was it because the short duration was not short enough to overcome the specific fuel consumption, or was it handling problems—perhaps in cases of engine failure—or was it installation problems when applied to the helicopter?

Figure 4 of the lecture showed the vibration level with various numbers of rotor blades, but this was for a rigid fuselage and, in fact, it was the coupling of the fuselage with rotor vibrations that was really the most serious.

Mr. Hafner: The fuel allowances to hover for 5 mins., which were sufficient for 2 to 3 landings, were given in Fig. 10 for all projects under comparison. They showed that such allowances were considerable in the case of direct lifting VTOL jets.

He had seen the Hiller ramjet helicopter in the U.S.A. There were no serious problems connected with installation or handling, but one problem was auto-rotation. The drag of the tip jets was considerable which gave a high sinking speed. However, the kinetic energy of such a rotor was relatively high and one could therefore pull up quickly and effectively from a high rate of descent. The outstanding advantage of the ramjet was its lightness and simplicity. There was a need for a simple unsophisticated type of helicopter. If it could be made for, say, £2,000 per passenger, one could sell a great number. The ram-jet offered this possibility.

Figure 4 was a summary of calculations based on rigid rotor blades and a rigid fuselage. The picture became of course, different when they introduced elasticities in the blades and in the fuselage. He intended to show the rapid reduction in vibration with increase in the number of blades. The dynamic response of the fuselage was of course important, and they could be worse off than the picture showed, but—and this was the point he wished to stress—they would never be better off.

Dr. E. Burke Wilford (President, Wilford Aircraft Corpn.): He had spent a great deal of his time connected with rotary wings; he had worked with the Piasecki and Vertol companies among others.

He was particularly interested now in the Convertiplane. The fundamental thing was to fly, not to get up and down. The VTOL type was primarily a fixed-wing aeroplane; it used its tilt wing and rotor only for the moment of take-off and landing.

If the wing of an aeroplane were just sufficient to fly properly at cruising speed they could save half the wing weight and 60 per cent of the span; if they designed just for *flying* they could save 20 per cent of the empty weight or 12-14 per cent of the gross weight.

To get up and down, they could have a rotor, a highly loaded propeller, direct jet. As a helicopter man he felt that if they could get round the Coriolis effect even the fixed-wing people would realise that rotors were very reliable. If they could unload them, stop them, retract them, in 1970 say, the medium of transport, particularly in short haul air lines, and in air mobility, would be convertiplanes or helicopters and they would be the largest part of the aircraft industry. Aeroplanes would be obsolete except for very large sizes.

They, in the inner circle, were contemplating rotary wing aircraft as high as a Mach number of 3—the RVTOL, Rotary vertical take-off and landing. They must not limit the rotary wing aircraft to the subsonic field but must go the whole way.

F. S. Wood (Senior Scientific Officer, Structures Dept., R.A.E., *Assoc. Fellow*): From the noise viewpoint, Mr. Hafner had said that no aircraft would be able to operate into city centres unless the disc loading was less than 25 lb./ft.^{2} This meant that everything but helicopters and convertible helicopters was excluded. Would Mr. Hafner confirm this?

Again, if disc loading were to be limited to 25 lb./ft.^{2} and the aircraft was of 50,000 lb. with two rotors, then the rotor diameter would be at least 30 ft., which was characteristic of a helicopter rotor rather than a propeller. So for city-centre operation, the helicopter was very much in the picture.

Mr. Hafner had shown curves of optimum parameters for helicopters of various powers. A quick look at the disc areas showed that all the present helicopters, including the Belvedere, Rotodyne, and so on, had rotors that were too small, *i.e.* disc loadings that were too high.

He would like to see evidence of the alleged effects of an increase in the number of blades on vibration. Up to the present time this had been entirely masked by the response of the elastic helicopter as a whole. Was there any evidence that the claims made by the author, and a few years ago by Mr. Fitzwilliams, were valid?

Mr. Hafner: First, on noise; the argument was straightforward. He would reiterate that if they accepted as maximum permissible noise level that shown in Fig. 2 (about 90 dB), and if they accepted the usual relationship between disc loading and noise, then 25 lb. per sq. ft. was the intersection point of these two lines. He thought there was little possibility of noise attenuation: unfortunately a good deal of noise could be made with very little energy and one could not see how to suppress this energy. He was convinced that the shrouded disc would not go into city centres unless there were new regulations. Even then they would have to go from about 25 lb. per sq. ft. to 500 lb. per sq. ft., and he thought this gap was too great, except, perhaps, for military use.

It was true that practical solutions showed rotors on the small side, but the optima were not very sharp, so they were really not far off the optimum. The practical results were probably due to the weight of the helicopter growing during design, but not the rotor diameter. The point being made was that if one went from a light helicopter to a heavy helicopter, one did not go from a small rotor to a large rotor, rather from a low disc loading to a high disc loading. That was the effect of scale that he wanted to illustrate.

On vibration. Using the motor car analogy, a six-cylinder engine was smoother running than a four-cylinder engine. That did not mean that one could disregard the problem of resonance with any of these engines, but everything else being equal they were much better off with six cylinders than with four.

O. L. L. Fitzwilliams (Chief Engineer and Special Director, Westland Aircraft, *Fellow*): He did not understand the viewpoint on ram-jets. Experience on the Kolibri showed that the handling was excellent.

Also, he could not understand the author's remarks about simple helicopters. There were three on the market in the U.S.A. now at about £3,000 per passenger.

The vibration shown on the graphs was vertical, *i.e.* along the axis of the shaft. The vibration in the plane of the rotor was the unpleasant one and this could be reduced.

He could not understand the comparison between the Fairey Ultra Light and the Bristol VTOL; the field was too broad and he was puzzled about the author's selection in that he omitted from the general survey such things as the Breguet 941.

They had built helicopters with such poor inertia in their rotors that they were unable to stop themselves safely and easily in vertical descent. Therefore, following B.E.A.'s experience, they had been led to accept long, shallow approach paths which were more appropriate to STOL aircraft.

The lecture had been a useful investigation but they were still only at the beginning.

Dr. J. P. Jones (University of Southampton): Surely whether vertical or horizontal vibration was the important one was a function of the layout of the helicopter. With a long thin tubular structure such as that of the Bristol machine the passengers and crew would be more likely to experience vertical vibration. But with the layout of a typical Westland aircraft the crew in fact could experience fore-and-aft vibration as a result of a vertical vibration of the fuselage.

The parameter λ/θ which occurred in the curves (=0·55), was constant, but with families of two to six blades could it be kept constant over the large working range of μ?

One of the ways of reducing vibration was to get Locke's number down. This could be done by going high because it went down with density. Had this been thought of?

On the 199 project; with the very large forward propellers they seemed to have gone back a step and put the blades opposite 10 passengers. They were very wide blades anyway. Would it be possible to turn the propellers into pushers and thus make the noise unbearable only in the lavatory?

Mr. Hafner: The present paper was a by-product of a paper on VTOL aircraft requested by the Aeronautical Research Council, hence there was nothing on short take-off and landing. VTOL, he thought, was a wide enough problem. He had included for comparison a number of types, diverse in shape and performance, in order to cover the field of VTOL. The VTOL aircraft was a hybrid characterised by two different regimes of flight. Hence there must be a compromise in meeting both requirements and skill in this was most important. That was the cohesive element in his paper, although the types of aircraft differed.

As to vibration he agreed he had given only an elementary picture of rigid body movement in the vertical direction. However, the picture for the in-plane movement would be similar. He had demonstrated that, as the number of blades increased, vibration decreased progressively. This was a factor of primary order in the design of high speed helicopters.

The information in Fig. 4 was related to a λ/θ value of 0·55 which was typical of a helicopter. For reduced values of λ/θ or for negative values (auto-rotating rotor) the vertical acceleration was reduced to about the half values given in Fig. 4. This was in fact the case that could be made for the high speed autogyro. He was convinced, however, that the improvement in vibration achieved from increasing the number of blades was much greater than that from reducing λ/θ. There was, however, a practical limit to the number of blades, because manufacturing tolerances were another source of vibration and the vibration level from this source in the rotor with a large number of blades would completely swamp the vibration referred to in Fig. 4.

He agreed that it was desirable to reduce Locke's number, which could be achieved by either reducing density or increasing blade weight.

He thought it was easier in an aircraft to shift the lavatory than the rotors!

Professor J. A. J. Bennett (Professor of Aerodynamics and Deputy Principal, College of Aeronautics, *Fellow*, Chairman): A way of compensating for manufacturing tolerances was to tune the rotor in flight. A few years ago they had listened to a paper before the Helicopter Association on "Tuning the Rotor," a particular technique of which used mirrors at the tips of the blades for reflecting light. At a recent short course on Helicopters held at Cranfield, someone from Bristol's had said that this had been known to make the rotors rougher. Would Mr. Hafner like to comment on this?

The Hiller Hornet had no difficulty in auto-rotating at very high sinking speeds, and some pilots even preferred high rates at descent with so much kinetic energy available in the rotor. It was just a question of operating sooner the collective pitch lever prior to landing. The Hornet was not used more, simply because of its high fuel consumption.

He had been considering the title of Mr. Hafner's lecture and thought perhaps the Jump Take-off Autogiro was really the first VTOL aircraft.

A Speaker: As a practical pilot he was delighted to hear that the rate of descent of 5,000 ft./min. did not worry them at all!

He was still not clear about additional vibration due to increased coning angle at high forward speed. Was this a separate factor, or was it the onset of the stall on the retreating blade? In either case, was there a case for increasing the minimum permissible rotor speed with all-up weight?

Mr. Hafner: Tuning in flight was certainly an advanced method of compensating for manufacturing tolerances. If, however, one went about this technique in the wrong way, then one would probably obtain a rougher rotor.

A Speaker: If they went to the maximum all-up weight and still had a good forward speed, was it desirable therefore to increase the minimum rotor r.p.m.—in other words, to keep the coning angle down?

Mr. Hafner: The ideal way to deal with high forward speed, he thought, was first to unload on to a fixed wing, because in doing so, they were: (*a*) decreasing rotor lift and vibratory forces scaled down with lift, and (*b*) were decreasing the coning angle, which also reduced vibration. Secondly, to increase the number of blades to about six.

V. A. B. Rogers (Chief Structural Engineer, Fairey Division, Westland Aircraft, *Assoc. Fellow*): Mr. Hafner had said that "all things being equal" one obtained the results he had shown in the paper. In helicopter airframes, all things *were* equal in that the body natural frequencies were fixed and they were not changed by changing the number of blades. So, all things were *not* equal in regard to the response of the rotor to a changing forcing frequency. So one could get to a state where, with a given number of blades, one was out of resonance, but by increasing the number one was then in resonance.

It was a very different job to shift airframe natural frequencies and he thought it was an over-simplification to say that the vibrations would go down as they put up the number of blades.

Mr. Hafner: He agreed that it was a difficult problem to avoid resonance, but stressed that the forcing term of the equation was reduced substantially with increase of the number of blades.

Dr. H. Roberts (Research Manager, Fairey Division, Westland Aircraft, *Fellow*): He wished to refer to the diagram of fuel consumption versus engine weight. In high fuel consumption engines, small changes in fuel consumption could produce large changes in optimum condition. With half-hour endurance and with a change (20 per cent) in fuel consumption, the half hour became an hour or even more. The fuel consumption used must be really representative.

On esoteric engines, it was a pity that in the diagram the tip-turbine engine was close to the ramjet because the one thing they were not, was close together. The tip turbine was used on a large rotor, the other on a small rotor. The turbine could not be put on a small rotor because of high g.

On the diagram of induced velocity as a function of disc loading, he was surprised to see only a single curve. With high disc loadings, the only way of getting it was by hot jets. The temperature of the hot jet, up to 2,000°, would modify the induced velocity greatly, by a factor of 2 or more, so instead of a nice simple curve one got a rapidly expanding band at these extra high disc loadings.

On the diagram of optimum loadings, Mr. Hafner said that the tangent to the curve where it had a maximum value was the best answer. In fact, the best answer was when the angle of the radius vector from the origin was maximum. The diagram was a little misleading.

On the question of maximum disc loadings consistent with certain noise levels, there were two implied assumptions. One, the machinery noise was ignored. Two, an arbitrary noise level of 90 dB had been taken. The slope of the curve was such that a small change in decibels would produce a large change in the possible disc loadings. He thought that it was risky to say that 90 dB was all right but not 95. There was, in fact, a large scatter band on permissible disc loadings. The result might be higher disc loadings than those quoted. Also, machinery noise might swamp all others and restrict the value of the curve.

Mr. Hafner: He had been concerned in his paper with the discussion of general trends only, to have included more detail would have meant losing this general view.

The line showing the induced flow as a function of at 25 lb. per sq. ft. disc loading, the average. The buried that temperature effects at high disc loading end would have a fundamental bearing on the induced velocity. However, the *order* was right. The same applied to the curve of noise level plotted against disc loading. The band was broad. The number of helicopters shown gave an idea of the scatter band. The threshold line intersected at 25 lb. per sq. ft. disc loading, the average. The buried rotor disc would require a disc loading of at least 500 lb. per sq. ft. This was a wide gap which could not be breached by scatter.

On the question of optimum loads he was not sure that Dr. Roberts quite understood the presentation. The optimum was the one that gave the best ratio between all-up weight and payload. That meant that one must connect a point on the curve with a point, not at the origin, but on the x-axis, upwards from the origin, far enough removed to allow for the weight that would be consumed in fuel for a given duration of flight. The flight assumed was a typical helicopter flight of one hour, with stand-off allowance, and so on. So for various engine sizes, they could calculate fuel weight, and then the line was drawn from that point which made this line a tangent to the curve. Consequently the slope of this curve was the significant slope; the ratio of all-up weight to disposable load less fuel.

Dr. H. F. Winny (Chief Designer, Fairey Division, Westland Aircraft, *Fellow*): Fig. 5 showed the ballast weight required on the rotor. This meant that if tip jet units were used as on the Rotodyne they would supply some of the ballast weight and therefore a diagram of payloads plotted against all-up weight would show more advantage for a rotating wing aircraft of this type. It followed that the disc loadings of 7·2 lb./ft.^{2} for the bigger aircraft might be increased because the payload could be increased by virtue of the tip jet unit acting as ballast.

Mr. Hafner: He agreed, but the comparison in Fig. 6 was based on many factors besides those in Fig. 5, for example, weight of transmission was taken into account. All these factors were subject to scale effect and with very large rotors they became very heavy indeed. Similar calculations could be made for other types of drive, such as in the Rotodyne. The general conclusions would be the same, but the optima would be on different points. The results might well be on the lines indicated by Dr. Winny. He agreed that if they could utilise useful components, such as tip engines as rotor ballast weight, that would be a good design feature. The weight must be there in one form or another to keep the coning angle down.

Dr. Wilford: He was a member of the Society of Convertible Aircraft Pioneers in America which met every three years. This year they had sponsored an unclassified convertiplane VTOL competition for all the three services. The specifications were: weight 35,000 lb.; cruising speed 250-300 m.p.h.; range 250 miles out and back; load 4 tons. In other words about a 40-passenger machine.

This was a most important competition which should result in the development of six prototypes, two for each of the three armed services and which possibly might spread to N.A.T.O. They looked for air mobility for perhaps one quarter of all their armed forces. The machine must be small so that it could be carried in their aircraft carriers and because the hangar depth was 18 ft. the machine must be 17 ft. only.

Professor Bennett (Chairman): This was an important paper, especially at the present juncture when many different VTOL aircraft of fundamental principles similar to the helicopter were being considered. They were on the verge of an era of powered lift and in fact the whole future of aviation was now tending to depend on powered lift, in one form or another.

TECHNICAL NOTES

Augmenting Aerodynamic Lift with Jet Lift

PAUL D. ARTHUR, B.S., M.S., Ph.D.*
and
EDWARD T. PITKIN, B.S., M.S.†
(*Consultant in Astronautics; †Manager, Space Propulsion Department, ASTRO, A Division of the Marquardt Corporation, Van Nuys, California)

NOTATION

A_0	engine capture area
C_D	drag coefficient
C_F	thrust coefficient
C_L	lift coefficient
D	drag of vehicle
e	effective
F_0, F_j	inlet, exit momentum flux
g	acceleration due to gravity
L	lift of vehicle
m	mass of vehicle
q_0	dynamic pressure
r	radius to centre of earth
V	vehicle velocity
V_c	circular orbital velocity
$\dot{V}$	velocity time derivative
α	angle of attack
ϕ	jet deflection angle from horizontal

Downward deflection of a propulsive jet may be employed to augment aerodynamic lift in an advantageous manner. In each situation there occurs a simple optimisation when the losses due to reduced propulsive efficiency are contrasted with the gains which accrue from jet lifting. Typical cases will be considered here for wing dominant configurations, *i.e.* cases where the lifting surfaces contribute most of the drag, with the body contributing but a minor effect. Variable geometry of both airframe and engine is implicitly assumed so that results may be applied to preliminary design studies which will determine the relative propulsion system size and wing area.

Consider a vehicle in essentially level flight without pitching acceleration. The force balance is given in Fig. 1. Forces include: centrifugal due to earth curvature, gravitational, and that due to longitudinal acceleration from thrust. The momentum flux balance for the propulsion system yields F_0, the inlet force and F_j, the exit force inclined at an angle ϕ to the horizontal. It is assumed that the exhaust nozzle is correctly expanded so that no pressure terms arise. The aerodynamic lift and drag complete the force inventory.

Equating forces in the vertical direction gives:

$$L+F_j\sin\phi=mg-mV^2/r=mg\left[1-\left(\frac{V}{V_c}\right)^2\right] \quad (1)$$

where $V_c=(gr)^{1/2}$, the circular satellite speed. This parameter, although a function of altitude, varies less than two per cent within the atmosphere, so it will be taken as a constant. The horizontal force balance gives

$$D+F_0+m\dot{V}-F_j\cos\phi=0. \quad (2)$$

Originally Received 5th May 1961.

The thrust coefficient is defined by

$$C_F q_0 A_0=F_j-F_0 \quad (3)$$

where it is noted that

$$F_0=2\,q_0 A_0. \quad (4)$$

q_0 is the free stream dynamic pressure and A_0 is the capture area or free stream-tube area of the flow into the propulsion system. External drag on the engine is assumed to be absorbed by the airframe drag. The ability to maintain an arbitrary lift/drag ratio arises through the artifice of a completely variable geometry. The lift and drag coefficients are similarly based on capture area for consistency.

$$C_D q_0 A_0=D \quad (5)$$

$$C_L q_0 A_0=L \quad (6)$$

Combining the above relations in terms of the coefficients gives

$$(C_F+2)\cos\phi-(C_D+2)=\frac{m\dot{V}}{q_0 A_0}. \quad (7)$$

Range Maximisation

If the Breguet range equation is derived for the jet lift case, the ordinary aerodynamic lift/drag ratio is replaced by an effective value which is the ratio of vehicle weight to internal thrust of the propulsion system

$$\left(\frac{L}{D}\right)_e=\frac{mg}{F_j-F_0}. \quad (8)$$

Using equations (1) through (6) this becomes

$$\left(\frac{L}{D}\right)_e=\frac{C_D L/D+(C_F+2)\sin\phi}{C_F\left[1-\left(\frac{V}{V_c}\right)^2\right]}. \quad (9)$$

The effective lift/drag ratio may be maximised either at constant thrust or drag coefficient. Range is maximised concurrently. Holding C_F constant means that the propulsion system performance parameters and therefore F_0 and F_j are maintained while the drag varies as required

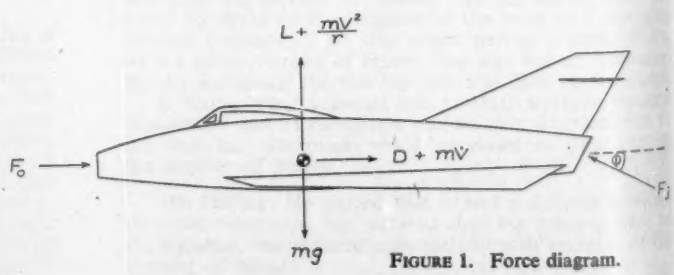


FIGURE 1. Force diagram.

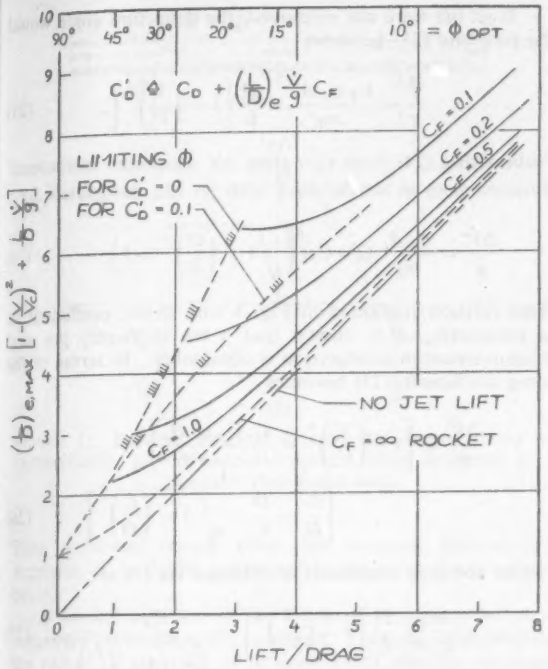


FIGURE 2. Increased effective L/D due to optimum jet lift; C_F constant.

by (2). For best aerodynamic efficiency the vehicle should always be at the angle of attack for maximum aerodynamic lift/drag ratio. The variation in drag coefficient then means that the wing area is changing with respect to the reference area, the engine capture area.

To maximise at constant C_F, first eliminate C_D using Equation (2)

$$\left[1-\left(\frac{V}{V_e}\right)^2\right]\left(\frac{L}{D}\right)_e=\left(1+\frac{2}{C_F}\right)\left(\frac{L}{D}\cos\phi+\sin\phi\right)-\frac{1}{C_F}\frac{L}{D}\left(2+\frac{m\dot{V}}{q_0 A_0}\right) \quad . \quad (10)$$

and by means of (3) and (8)

$$\left(\frac{L}{D}\right)_e=\frac{\left(1+\frac{2}{C_F}\right)\left(\frac{L}{D}\cos\phi+\sin\phi\right)-\frac{2}{C_F}\frac{L}{D}}{1-\left(\frac{V}{V_e}\right)^2+\frac{L}{D}\frac{\dot{V}}{g}} \quad . \quad (11)$$

This is maximised with respect to ϕ with constant C_F, L/D, V, and $\dot{V}$ when

$$\phi_{opt}=\cot^{-1}\left(\frac{L}{D}\right) \quad . \quad (12)$$

The corresponding effective lift/drag ratio at ϕ_{opt} is

$$\left(\frac{L}{D}\right)_{e,\,max}=\frac{\left(1+\frac{2}{C_F}\right)\sqrt{1+\left(\frac{L}{D}\right)^2}-\frac{2}{C_F}\frac{L}{D}}{1-\left(\frac{V}{V_e}\right)^2+\frac{L}{D}\frac{\dot{V}}{g}} \quad . \quad (13)$$

To appreciate the magnitude of ϕ_{opt}, note that the angle of attack at maximum L/D in linear wing theory is

$$\alpha_{opt}=\frac{1}{2\,(L/D)_{max}}\approx\frac{1}{2}\phi_{opt} \quad . \quad (14)$$

for small angles. Equations (12) and (14) have been developed in Ref. 1. At hypersonic speeds the simple Newtonian flow theory yields, for small angles

$$\alpha_{opt}=\frac{2}{3\,(L/D)_{max}}\approx\frac{2}{3}\phi_{opt} \quad . \quad (15)$$

When the acceleration is zero and $V/V_e\ll 1$, (13) reduces to the result of Ref. 2. The relation between effective lift/drag ratio and aerodynamic lift/drag ratio is given in Fig. 2 with C_F as a parameter and optimum jet deflection angles indicated. Note that the improvement is largest for low values of thrust coefficient. The lowest values of C_F will be precluded, however, by the requirement to overcome external drag and provide accelerating thrust, even in the case of a flying engine. Limit lines for the drag coefficient modified as

$$C_D'=C_D+\left(\frac{L}{D}\right)_e\frac{C_F\dot{V}}{g} \quad . \quad (16)$$

are therefore superimposed upon the figure. The advantage of jet lift was also recognised in Ref. 4 where a specific example was given without analytical optimisation. This numerical result is contained in Fig. 2 at $L/D=5$.

As the wing area is decreased to zero, only body lift and drag remain. Variation of these parameters with respect to the force applied by the jet can no longer be maintained. Thus there is no optimisation of jet-versus-aerodynamic lift and the jet deflection angle is uniquely specified by Equation (2) with the drag value corresponding to the maximum L/D situation.

If, as an alternative to the above formulation, the effective lift/drag ratio is to be maximised with a constant drag coefficient, the propulsion system performance, *i.e.* F_j, must be allowed to vary. The thrust coefficient is first eliminated from (9) by means of (7),

$$\left(\frac{L}{D}\right)_e=\frac{C_D\frac{L}{D}\cos\phi+\left(2+C_D+\frac{m\dot{V}}{q_0 A_0}\right)\sin\phi}{\left[1-\left(\frac{V}{V_e}\right)^2\right]\left[2+C_D+\frac{m\dot{V}}{q_0 A_0}-2\cos\phi\right]} \quad . \quad (17)$$

Again optimising with respect to ϕ, holding $\dot{V}$, V, C_D and L/D constant, gives an implicit relation for the optimum deflection angle,

$$\left[2+C_D+\frac{m\dot{V}}{q_0 A_0}\right]\cos\phi_{opt}-C_D\frac{L}{D}\sin\phi_{opt}-2=0 \quad . \quad (18)$$

Substitution of (18) into (17) yields the maximum effective lift/drag ratio as

$$\left(\frac{L}{D}\right)_{e,\,max}=\frac{\operatorname{cosec}\phi_{opt}}{1-\left(\frac{V}{V_e}\right)^2} \quad . \quad (19)$$

The corresponding value of thrust coefficient at the optimum condition is

$$C_F=\left[\frac{m\dot{V}}{q_0 A_0}+C_D+2\right]\sec\phi_{opt}-2. \quad . \quad (20)$$

These results reduce to those of Ref. 3 when $\dot{V}=0$ and $V/V_e\ll 1$.

Maximisation of Acceleration

It may sometimes be necessary to design for maximum horizontal acceleration. Here the aerodynamic induced drag may be decreased somewhat by carrying a portion of

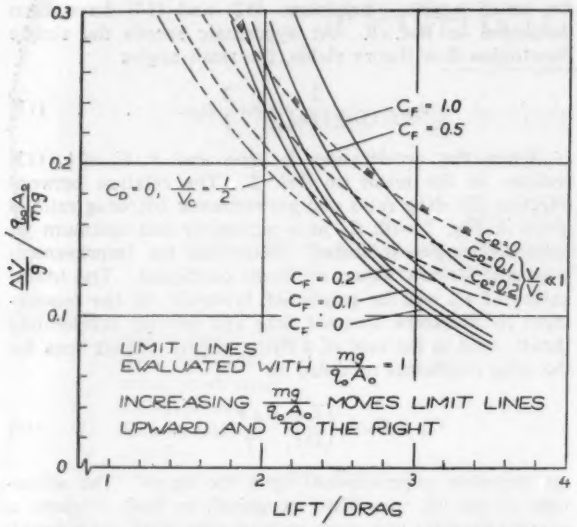


FIGURE 3. Increased acceleration due to optimum jet lift; C_F constant.

the vehicle weight with jet lift. First solve (7) for acceleration, combine with (1) and introduce the aerodynamic lift/drag ratio.

$$\frac{\dot{V}}{g} = \frac{C_F q_0 A_0}{mg}\cos\phi - \frac{F_0}{mg}\left[1 - \cos\phi - \frac{D}{L}\sin\phi\right] - \frac{D}{L}\left[1 - \left(\frac{V}{V_c}\right)^2 - \frac{C_F q_0 A_0}{mg}\sin\phi\right] \quad . \quad . \quad (21)$$

The acceleration is then maximised with respect to the deflection angle with all other parameters held constant. Again wing area is implicitly assumed to vary with jet deflection angle so that both the horizontal and vertical force balances are always satisfied. (Again there is no optimum jet deflection angle for wingless bodies, where ϕ is uniquely specified by solution of Equation (2)). The optimum deflection angle will again be

$$\phi_{opt} = \cot^{-1}\left(\frac{L}{D}\right) \quad . \quad . \quad . \quad . \quad (22)$$

and the corresponding maximum acceleration is then

$$\frac{\dot{V}}{g} = \frac{q_0 A_0}{mg}\left[(2+C_F)\sqrt{1+\left(\frac{D}{L}\right)^2} - 2\right] - \frac{D}{L}\left[1 - \left(\frac{V}{V_c}\right)^2\right] \quad . \quad . \quad (23)$$

If jet lift were not employed, the deflection angle would be zero and (21) becomes

$$\frac{\dot{V}}{g} = \frac{C_F q_0 A_0}{mg} - \frac{D}{L}\left[1 - \left(\frac{V}{V_c}\right)^2\right] . \quad . \quad (24)$$

Subtracting (24) from (23) gives the maximum incremental improvement in acceleration with jet lift, designated $\Delta\dot{V}$:

$$\frac{\Delta\dot{V}}{g} = \frac{q_0 A_0}{mg}(2+C_F)\left(\sqrt{1+\left(\frac{D}{L}\right)^2} - 1\right) . \quad . \quad (25)$$

This relation is plotted in Fig. 3 with thrust coefficient as a parameter. It is shown that a ten to twenty per cent improvement in acceleration is obtainable. In terms of the drag coefficient, (25) becomes

$$\frac{\Delta\dot{V}}{g} = \left[1 - \left(\frac{V}{V_c}\right)^2 - \frac{L}{D}\frac{C_{D_1} q_0 A_0}{mg}\right] \times \left[\frac{L}{D} + \frac{D}{L} - \sqrt{1+\left(\frac{L}{D}\right)^2}\right] \quad . \quad (26)$$

where the drag coefficient is obtained via (7) as:

$$C_{D,\,opt} = \frac{mg}{q_0 A_0}\frac{D}{L}\left[1 - \left(\frac{V}{V_c}\right)^2\right] - \frac{C_F + 2}{\frac{L}{D}\sqrt{1+\left(\frac{L}{D}\right)^2}} . \quad (27)$$

Limiting values of minimum drag coefficient for the low velocity case are indicated in Fig. 3. The optimum from (27) must fall above these values for (25) and (26) to be valid.

REFERENCES

1. LUIDENS, R. W. (1959). Arrangements of Jet Engine and Airframe for Increased Range, NACA RM E56L04, 26 July 1957 (Declassified February 1959).

2. ARTHUR, P. D. and MCJONES, R. W. (1957). Effective Lift/Drag Ratio with Jet Lift, *Jet Propulsion* Vol. 27, No. 6, p. 676, June 1957.

3. MAGER, A. and BAKER, J. (1958). Optimum Effective Lift/Drag Ratio with Jet Lift, MR 20,003, ASTRO, A Division of The Marquardt Corporation, October 1958.

4. LUSKIN, H. and KLEIN, H. (1955). The Influence of Turbojet Airflow on the Aerodynamic Design of Airplanes, SM-19111, Douglas Aircraft Co., Santa Monica Division, June 1955.

Optimum Support Position for Flat Plate Subjected to Pressure

R. KITCHING

(Department of Mechanical Engineering, Manchester College of Science and Technology)

WHEN a circular plate of constant thickness is simply supported on a concentric ring and is subjected to a uniform normal pressure, there is a radius for the supporting ring giving optimum bending stress conditions in the plate. Assuming the plate deflections are small, it is concluded that the required supporting ring radius varies between 70·1 and 73·0 per cent of the outside radius of the plate, depending on the value of Poisson's Ratio for the plate material.

Received 1st May 1961.

INTRODUCTION

A familiar problem in beam theory is to position two simple supports, A and B, to give optimum bending stress conditions for an elastic beam of uniform cross section subjected to a uniformly distributed transverse load (*see* Fig. 1*a*). The bending moment diagram for this situation is as shown in Fig. 1*b*; the required optimised condition is given when the bending moment, M, under a support is equal in value but opposite in sense to that at the centre of the beam.

i.e. $|M_A| = |M_B| = |M_C|$

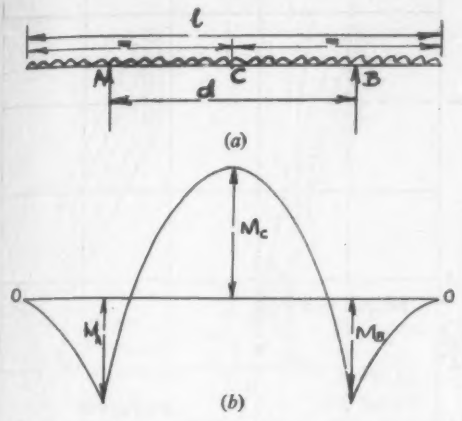


FIGURE 1. Bending moment diagram for beam resting on symmetrically placed simple supports, when subjected to a uniformly distributed load.

This condition occurs when the distance between the supports, d, is 0·586 l, where l is the total length of the beam.

A similar problem arises for a uniform circular plate supported on a simple ring support. The requirement is for the radius of the ring to be such as to produce optimum bending stress conditions when the plate is subjected to uniform normal pressure.

NOTATION

p	normal pressure on plate
a	outside radius of plate
b	radius of supporting ring for plate
r	distance of any point on plate from the centre
M_r	radial bending moment on plate per unit length
M_t	tangential bending moment on plate per unit length
$\|M_r\|$	numerical value of M_r, etc.

ANALYSIS

The problem may be tackled by superposing the effect of two common loading cases* as shown diagramatically in Fig. 2.

For condition (b)

The radial bending moment per unit length at any radius r,

$$M_r = \frac{p}{16}(3+\nu)(a^2-r^2) \quad . \quad . \quad (1a)$$

The tangential bending moment per unit length,

$$M_t = \frac{p}{16}[a^2(3+\nu)-r^2(1+3\nu)] \quad . \quad . \quad . \quad . \quad (1b)$$

For condition (c)

If r is between $r=b$ and $r=a$,

$$M_r = -\frac{a^2p}{8}\left[(1-\nu)\left(\frac{b^2}{r^2}-\frac{b^2}{a^2}\right)-2(1+\nu)\log\frac{r}{a}\right] \quad . \quad (2a)$$

$$M_t = -\frac{a^2p}{8}\left[(1-\nu)\left(2-\frac{b^2}{a^2}-\frac{b^2}{r^2}\right)-2(1+\nu)\log\frac{r}{a}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad (2b)$$

and if r is less than b

$$M_r = M_t = \frac{a^2p}{8}\left[2(1+\nu)\log\frac{b}{a}-\frac{(a^2-b^2)(1-\nu)}{a^2}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

For the combined condition of loading (a)

If r is greater than b, or equal to b

$$M_r = \frac{pa^2}{16}\left[(3+\nu)-\frac{r^2}{a^2}(3+\nu)-2(1-\nu)\left(\frac{b^2}{r^2}-\frac{b^2}{a^2}\right)+4(1+\nu)\log\frac{r}{a}\right] \quad . \quad . \quad (4a)$$

$$M_t = \frac{pa^2}{16}\left[(3+\nu)-\frac{r^2}{a^2}(1+3\nu)-2(1-\nu)\left(2-\frac{b^2}{a^2}-\frac{b^2}{r^2}\right)+4(1+\nu)\log\frac{r}{a}\right] \quad . \quad . \quad . \quad (4b)$$

and if r is less than b, or equal to b

$$M_r = \frac{pa^2}{16}\left[(3+\nu)-(3+\nu)\frac{r^2}{a^2}-2(1-\nu)\left(1-\frac{b^2}{a^2}\right)+4(1+\nu)\log\frac{b}{a}\right] \quad . \quad . \quad . \quad (5a)$$

$$M_t = \frac{pa^2}{16}\left[(3+\nu)-(1+3\nu)\frac{r^2}{a^2}-2(1-\nu)\left(1-\frac{b^2}{a^2}\right)+4(1+\nu)\log\frac{b}{a}\right] \quad . \quad . \quad . \quad (5b)$$

Typical distributions of M_r and M_t are shown in Fig. 3. There are three points where the bending moment per unit length may have the maximum numerical value for any given value of b. These are at $r=0$ and $r=b$ for $|M_r|$ and at $r=a$ for $|M_t|$.

Figure 4 shows the variation of M_r at $r=0$, M_r at $r=b$, and M_t at $r=a$ with the ratio $b:a$ when Poisson's ratio is

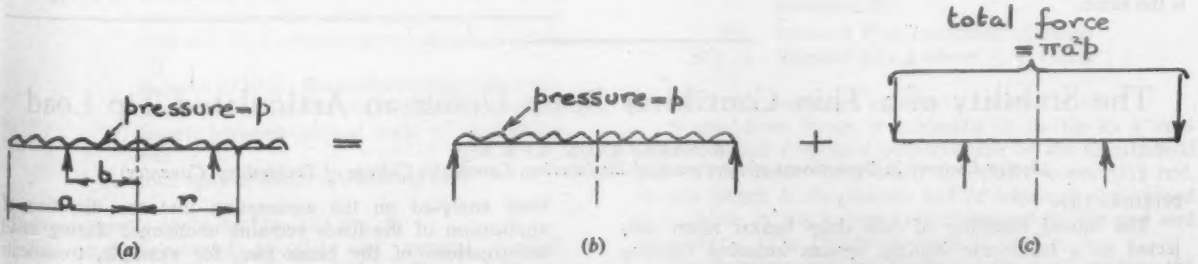


FIGURE 2. Loading condition (*a*) is combination of condition (*b*) and condition (*c*).

*TIMOSHENKO, S. *Theory of Plates and Shells*, McGraw Hill Book Co. (1st Edn.), pp. 61 and 70.

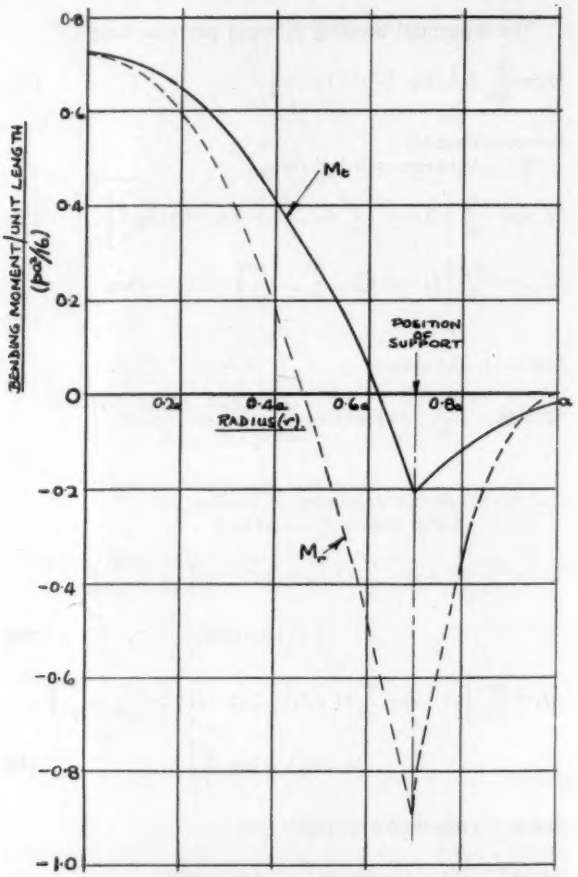


FIGURE 3. Distribution of radial and Tangential bending moments per unit length across plate. Poisson's ratio=0·3, support radius $b=0{\cdot}7a$.

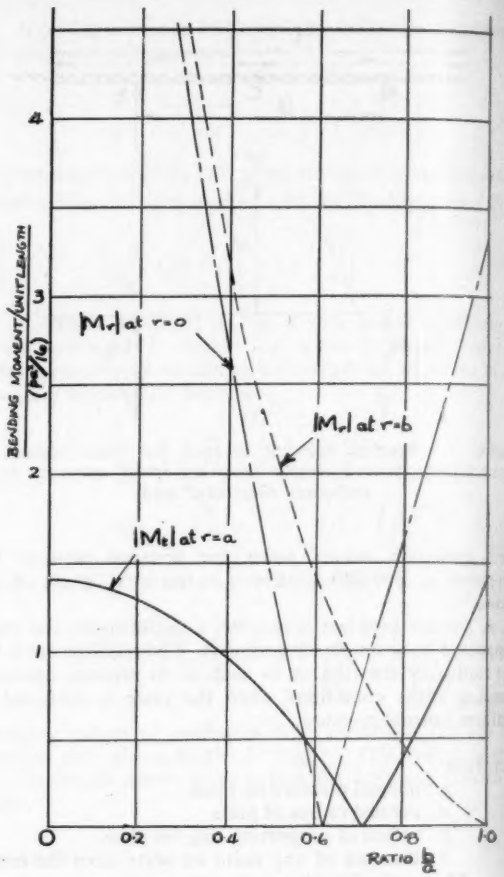


FIGURE 4. Variation with $\frac{b}{a}$ of $|M_r|$ at $r=0$
$|M_r|$ at $r=b$
$|M_t|$ at $r=a$
Poisson's Ratio=0·3.

0·3. It is immediately apparent that the value of b at which the highest overall numerical value of bending moment per unit length is smallest occurs when $|M_r|$ at $r=0$ is equal to $|M_r|$ at $r=b$.

CONCLUSION

The optimum position of the supports will be dependent upon Poisson's ratio and the table gives the required value of b in terms of a and the corresponding maximum bending moment per unit length for three different values of ν.

It is interesting to note that none of these values is far from $b=0{\cdot}707a$, which would correspond to the condition that the total load on either side of the supporting ring is the same.

ν	*Optimum value of b*	*Maximum bending moment per unit length*
0	$0{\cdot}730a$	$0{\cdot}800\ \frac{pa^2}{16}$
0·3	$0{\cdot}711a$	$0{\cdot}838\ \frac{pa^2}{16}$
0·5	$0{\cdot}701a$	$0{\cdot}862\ \frac{pa^2}{16}$

The Stability of a Thin Cantilever Beam Under an Articulated Tip Load

B. SARAVANOS, A.F.R.Ae.S.
(Senior Lecturer in Department of Aeronautical Engineering, Lanchester College of Technology, Coventry)

INTRODUCTION

The lateral buckling of thin deep beams when subjected to a transverse loading system inducing bending initially in the plane of maximum flexural stiffness has been analysed on the assumption that the direction of application of the loads remains unchanged during small deformations of the beam (*see*, for example, treatments in Refs. 1 and 2). A typical case of a beam so loaded is illustrated in Fig. 1.

Originally Received 20th April 1961.

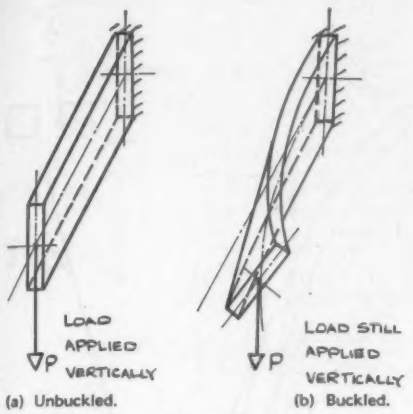


FIGURE 1.

Certain cases of beam loading, which have practical importance, occur for which this assumption is invalid. Such a case is that of an aircraft control circuit wherein a concentrated load is applied to a bellcrack lever by means of an articulated connecting rod. Thus, referring to Fig. 2, the end of the connecting rod remote from the lever or beam is constrained, *e.g.* by a tube running in rollers, to move in a direction perpendicular to the spanwise axis of the beam. Then, provided both ends of the connecting rod are fully articulated so that the rod can move without constraint out of the original plane formed by beam and rod, a component of the rod axial load will be induced by a small out-of-plane deformation of the beam. This component of load acts across the beam and tends to twist and bend it about its axis of least flexural stiffness. If the axial load in the rod is compressive its side-component will precipitate instability of the beam, if tensile it will retard instability, as compared with the results for the standard case, referred to above, in which the applied load remains unchanged in direction throughout the loading process.

The present work deals with the case of a cantilever beam of uniform thin rectangular cross-section subjected to a concentrated tip load applied by means of an articulated rod, as described above; the method of analysis used is based on the concept of static elastic stability.

NOTATION

Geometric Co-ordinates and Dimensions (*See also Fig.* 3)

x, y coinciding with the principal axes of beam cross-section before deformation. Origin at centroid of a cross-section distant w from tip

w coinciding with the spanwise flexural axis of beam before deformation. Origin at tip

ξ, η coinciding with the principal axes of beam cross-section after deformation. Origin at centroid of a cross-section distant w from tip

ζ tangent to beam flexural axis after deformation, at a cross-section distant w from tip

h length between pinned ends of connecting rod

L total span of beam in direction of w

Deformation Co-ordinates (*See also Fig.* 3)

u, v horizontal (x-axis) and vertical (y-axis) co-ordinates respectively defining deformation of flexural axis of beam at a section distant w from tip. Origin at centroid of cross-section before deformation

u_0/v_0 values of u and v at beam tip

β twist of beam after deformation at a section distant w from tip

β_0 value of β at tip

α inclination of connecting rod in plane xy at beam tip formed between y-axis and connecting rod after beam deformation

Material and Other Characteristics

E Young's modulus of elasticity of beam material

G shear modulus of beam material

J cross-section torsional characteristic defined in the expression for twist rate: $\frac{d\beta}{dw} = \frac{M_\zeta}{GJ}$

$I_{\eta,\xi}$ second moment of area of beam cross-section about η, ξ-axis

k constant defined by expression (7)

$J_v(---)$ Bessel Function of the first kind, of order v

$\Gamma(---)$ Gamma Function

Forces (*See also Fig.* 2 *and* 3)

P applied concentrated tip load acting at remote end of connecting rod in the y-direction

$P_v = P$ component in y-direction of connecting rod load acting through centroid of beam tip cross-section

$P_u \backsimeq \frac{u_0}{h} P$ component in x-direction of connecting rod load acting through centroid of beam tip cross-section

P_{CR} value of P at instability of beam

$M_{\xi,\eta,\zeta}$ moment acting about ξ, η, ζ-axis

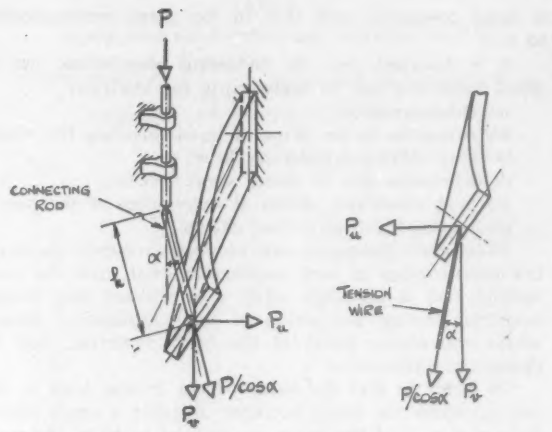


FIGURE 2.

CANTILEVER BEAM UNDER AN ARTICULATED TIP LOAD

A cantilever beam is subjected at its tip to a concentrated load P applied perpendicular to the longitudinal axis of the beam, via a freely articulated connecting rod, of true length h, the remote end of which is constrained to translate in the original plane formed by the rod and beam axes. The system is depicted in Fig. 3.

The bending induced thereby takes place, before the onset of buckling, in the plane where the flexural rigidity

is large compared with that in the plane perpendicular to it.

It is assumed that the following phenomena are of small order and can be neglected in the analysis:

second-order terms;

deformations in the plane of initial bending for which bending stiffness is relatively large;

deformations due to direct shear forces;

warping constraint effects at extremities of the beam, these being localised in their effects.

Other assumptions are that no irregularities in the beam nor eccentricities in load application exist; that the connecting rod is infinitely rigid; that stresses and strains occurring during the action of load application remain within the elastic limits of the beam material; that no dissipative forces occur.

In order to find the value of the critical load in the rod at which the beam becomes unstable a small lateral deformation u of the beam is assumed to have occurred, being a maximum u_0 at the tip. This deformation is accompanied by a twist β, which is a maximum β_0 at the tip. Equilibrium equations are then formulated, from which the smallest value of the applied load can be found to keep the beam in this slightly buckled shape. A compressive load in the rod will be assumed in the analysis.

Referring to Fig. 3, forces are resolved at a typical cross-section $a-a'$ of the beam distant w from the tip, after the latter has moved laterally through a small distance u_0. The vertical component of the load in the connecting rod is:

$$P_v = P \quad . \quad . \quad . \quad . \quad (1)$$

The lateral component is:

$$P_u \frown \frac{u_0}{h} P \quad . \quad . \quad . \quad (2)$$

The moments arising at section $a-a'$ from these components are resolved onto axes η, ζ and ξ. The equations of equilibrium of moments can then be expressed as follows:

$$M_\xi = EI_\xi \frac{d^2v}{dw^2} = Pw \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$M_\eta = EI_\eta \frac{d^2u}{dw^2} = Pw\beta + P\frac{u_0}{h} w \quad . \quad . \quad (4)$$

$$M_\zeta = -GJ \frac{d\beta}{dw} = P(u_0 - u) + Pw \frac{du}{dw} \quad . \quad . \quad (5)$$

By virtue of the assumptions described above, equation (3) can be ignored. The variable u is eliminated from equations (4) and (5), giving the following equation in terms of β only:

$$\frac{d^2\beta}{dw^2} + k^2w^2\beta + \frac{u_0}{h} k^2w^2 = 0 \quad . \quad . \quad (6)$$

$$\text{where: } k^3 = \frac{P^2}{GJEI_\eta} \quad . \quad . \quad . \quad (7)$$

The solution to this equation, in terms of Bessel Functions, is:

$$\beta = w^{\frac{1}{2}} \{AJ_{\frac{1}{4}}(\tfrac{1}{2}kw^2) + BJ_{-\frac{1}{4}}(\tfrac{1}{2}kw^2)\} - \frac{u_0}{h} \quad . \quad . \quad (8)$$

where A and B are constants of integration.

$$\text{Also: } \frac{d\beta}{dw} = kw^2 \{AJ_{-\frac{1}{4}}(\tfrac{1}{2}kw^2) - BJ_{\frac{1}{4}}(\tfrac{1}{2}kw^2)\} \quad . \quad . \quad (9)$$

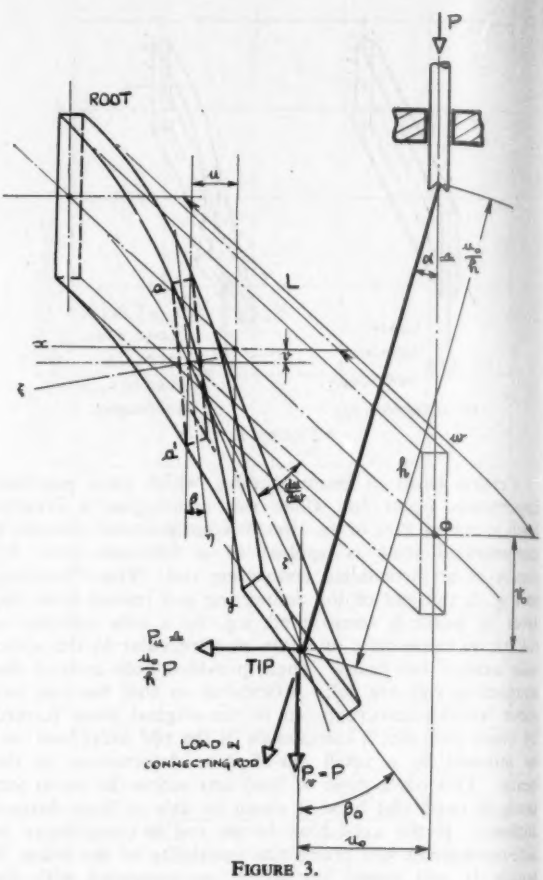


FIGURE 3.

Relevant boundary conditions are as follows:

$$[\beta]_{w=L} = 0 \quad . \quad . \quad . \quad (10)$$

$$\left[\frac{d\beta}{dw}\right]_{w=L} = -\frac{Pu_0}{GJ} \quad . \quad . \quad . \quad (11)$$

$$\left[\frac{d^2\beta}{dw^2}\right]_{w=L} = -k^2L^2 \frac{u_0}{h} \quad . \quad . \quad (12)$$

$$[\beta]_{w=0} \neq 0 \quad . \quad . \quad . \quad . \quad (13)$$

$$\left[\frac{d\beta}{dw}\right]_{w=0} = 0 \quad . \quad . \quad . \quad (14)$$

$$\left[\frac{d^2\beta}{dw^2}\right]_{w=0} = 0 \quad . \quad . \quad . \quad (15)$$

Conditions (10), (11) and (14) will be applied to equations (8) and (9). Noting that:

$$\left[\frac{d\beta}{dw}\right]_{w=0} = \underset{w \to 0}{\text{Lim.}} \left[kw^{\frac{3}{2}}\{AJ_{-\frac{1}{4}}(\tfrac{1}{2}kw^2) - BJ_{\frac{1}{4}}(\tfrac{1}{2}kw^2)\}\right] = \frac{2^{\frac{3}{4}}}{\Gamma(\frac{1}{4})} k^{\frac{1}{2}}A,$$

the stability criterion can be expressed as:

$$\begin{vmatrix} J_{\frac{1}{4}}(\frac{1}{2}kL^2) & J_{-\frac{1}{4}}(\frac{1}{2}kL^2) & -\dfrac{1}{hL^{\frac{1}{2}}} \\ J_{-\frac{1}{4}}(\frac{1}{2}kL^2) & -J_{\frac{1}{4}}(\frac{1}{2}kL^2) & \left(\dfrac{EI_\eta}{GJ}L^3\right)^{\frac{1}{4}} \\ \dfrac{2^{\frac{3}{4}}}{\Gamma(\frac{1}{4})}k^{\frac{1}{2}} & 0 & 0 \end{vmatrix} = 0 \quad (16)$$

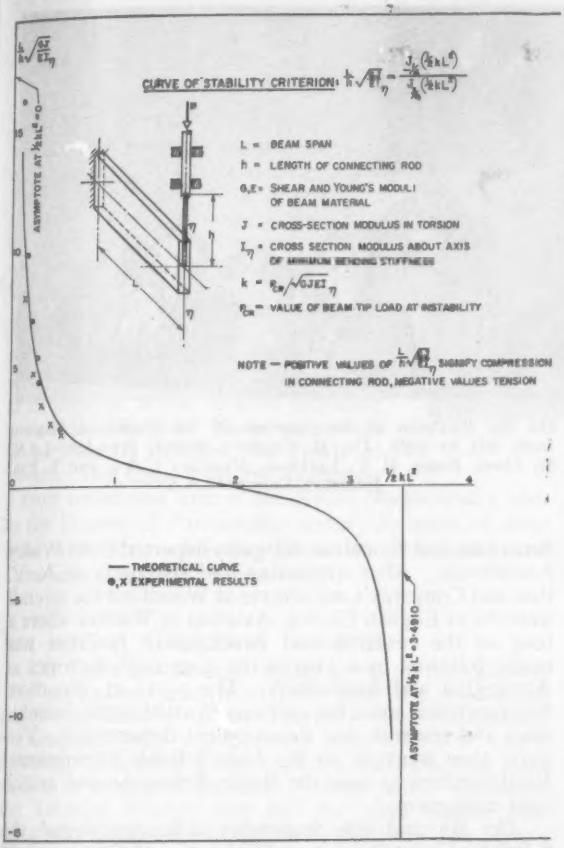

CURVE OF STABILITY CRITERION
L = BEAM SPAN
h = LENGTH OF CONNECTING ROD
G,E = SHEAR AND YOUNG'S MODULI OF BEAM MATERIAL
J = CROSS-SECTION MODULUS IN TORSION
I_η = CROSS SECTION MODULUS ABOUT AXIS OF MINIMUM BENDING STIFFNESS
k = P_CR/√(GJEI_η)
P_CR = VALUE OF BEAM TIP LOAD AT INSTABILITY
NOTE — POSITIVE VALUES OF (L/h)√(GJ/EI_η) SIGNIFY COMPRESSION IN CONNECTING ROD, NEGATIVE VALUES TENSION
ASYMPTOTE AT ½kL² = 0
ASYMPTOTE AT ½kL² = 3·4910
½kL²
THEORETICAL CURVE
⊕,X EXPERIMENTAL RESULTS

FIGURE 4. Stability of a cantilever beam under an articulated tip load.

This reduces to

$$\frac{L}{h}\left(\frac{GJ}{EI_\eta}\right)^{\frac{1}{2}} = \frac{J_{-\frac{1}{4}}(\frac{1}{2}kL^2)}{J_{\frac{1}{4}}(\frac{1}{2}kL^2)} \quad (17)$$

The remaining boundary conditions (12), (13) and (15) are also satisfied by the above solution.

Reverting to the criterion (17), which is dimensionless, a graphical representation is convenient as in Fig. 4. In this figure, expression (17) has been interpreted in such a way that positive values of $\frac{L}{h}\left(\frac{GJ}{EI_\eta}\right)^{\frac{1}{2}}$ correspond to compression in the connecting rod and negative values to tension. Corresponding numerical values for criterion (17) are also given in the table.

The magnitude P_{CR} of P under which a particular beam is unstable can be determined by evaluating the expression

$$\frac{L}{h}\left(\frac{GJ}{EI_\eta}\right)^{\frac{1}{2}}$$

from given characteristics and by reading from the curve the corresponding value of $\frac{1}{2}kL^2$. The value of P_{CR} is then obtained by means of expression (7).

It may be noted that the value of $\frac{1}{2}kL^2=2{\cdot}0063$ when

$$\frac{L}{h}\left(\frac{GJ}{EI_\eta}\right)^{\frac{1}{2}} = 0$$

is that obtained from the standard analysis of the system of Fig. 1. Evidently the load at instability will be larger when tensile than when compressive, when applied through an articulated rod.

TABLE I

VALUES ASSOCIATED WITH STABILITY CRITERION (17)

Positive values of $\frac{L}{h}\left(\frac{GJ}{EI_\eta}\right)^{\frac{1}{2}}$ correspond to compression in connecting rod, negative values to tension

$\frac{1}{2}kL^2$	$\frac{L}{h}\left(\frac{GJ}{EI_\eta}\right)^{\frac{1}{2}}$	$\frac{1}{2}kL^2$	$\frac{L}{h}\left(\frac{GJ}{EI_\eta}\right)^{\frac{1}{2}}$
0	$+\infty$	1·80	+ 0·204
0·05	+29·986	2·00	+ 0·00630
0·10	+14·971	2·0063	0
0·20	+ 7·443	2·20	− 0·201
0·30	+ 4·914	2·40	− 0·435
0·40	+ 3·635	2·60	− 0·725
0·50	+ 2·855	2·80	− 1·129
0·60	+ 2·325	3·00	− 1·792
0·80	+ 1·638	3·10	− 2·349
1·00	+ 1·198	3·20	− 3·264
1 20	+ 0·878	3·30	− 5·100
1·40	+ 0·624	3·40	−10·885
1·60	+ 0·405	3·4910	$-\infty$

The asymptotes associated with the curve of Fig. 4 can be identified by assigning values to $\frac{1}{2}kL^2$ from the condition that:

$$\frac{d\left[\frac{J_{-\frac{1}{4}}(\frac{1}{2}kL^2)}{J_{\frac{1}{4}}(\frac{1}{2}kL^2)}\right]}{d\left[\frac{1}{2}kL^2\right]} \to \infty \quad (18)$$

Carrying out the differentiation gives:

$$\left\{\frac{1}{\frac{1}{2}kL^2}\frac{J_{-\frac{1}{4}}(\frac{1}{2}kL^2)}{J_{\frac{1}{4}}(\frac{1}{2}kL^2)} - \left[\frac{J_{-\frac{1}{4}}(\frac{1}{2}kL^2)}{J_{\frac{1}{4}}(\frac{1}{2}kL^2)}\right] - 1\right\} \to \infty \quad (19)$$

When $\frac{1}{2}kL^2 \to 0$, this expression becomes infinite.

Also, since for $\frac{1}{2}kL^2=3{\cdot}4910$, $J_{\frac{1}{4}}(\frac{1}{2}kL^2)=0$ (*i.e.* the first zero of $J_{\frac{1}{4}}(\frac{1}{2}kL^2)$ and the corresponding value of $J_{-\frac{1}{4}}(\frac{1}{2}kL^2)$ is finite, then expression (19) also becomes infinite. Thus, asymptotes occur when $\frac{1}{2}kL^2=0$ and 3·4910.

The beam as envisaged in the foregoing analysis was tested statically, and the test results are embodied on the graph of Fig. 4 for the cases of compression in the connecting rod. Several beams were tested of different dimensions and in steel and aluminium alloy. The results of tests for cases of tension in the connecting rod are not yet completed satisfactorily. These will be included later after further work on the problem which it is intended to carry out.

ACKNOWLEDGMENTS

The physical phenomenon forming the subject of the present analysis was originally pointed out by Mr. A. H. Crawshaw, of Blackburn Aircraft Ltd. The experimental work and part of the theoretical analysis were conducted at the Technical College, Coventry, and at the Lanchester College of Technology, Coventry. The views expressed in this paper are those of the author.

REFERENCES

1. TIMOSHENKO, S. (1936). *Theory of Elastic Stability* 1st Edition, 1936. McGraw-Hill.
2. TEMPLE, G. and BICKLEY, W. G. (1933). *Rayleigh's Principle and its Applications to Engineering*, 1st Edition, 1933. Dover Publications (1956).
3. *Tables of Bessel Functions of Fractional Order.* Prepared by the National Applied Mathematics Laboratories, National Bureau of Standards, U.S.A., 2 Vols., 1947-48. Columbia University Press, New York, N.Y., U.S.A.

Eighth Anglo-American Aeronautical Conference

3RD-14TH SEPTEMBER 1961

The 1961 Anglo-American Aeronautical Conference was an outstanding one. For the first time the Canadian Aeronautical Institute joined the Society and the Institute of the Aerospace Sciences as a full member of the Conference in England and, because of the new Lecture Theatre, the Society was able to hold all the technical sessions and most of the social functions at its own headquarters in London. Altogether some 570 delegates attended the Conference including about 80 U.S. delegates and eight Canadians. A number of the Americans were accompanied by their wives.

Messages wishing the Conference every success were received from Her Majesty The Queen, as Patron of the Society, from H.R.H. The Prince Philip, Duke of Edinburgh, Patron of the Canadian Aeronautical Institute, and from Mr. Kennedy, President of the United States of America.

The Conference began with a reception and cocktail party for all delegates and their wives in the Lecture Theatre on Sunday evening, 3rd September. For the next week, thanks to the courtesy and co-operation of the Industry and the Ministry of Aviation, Canadian and American delegates had a full programme of visits to firms in the Aircraft Industry and to Government establishments.

Programme of Visits

A full week of visits began on Monday, 4th September. In a Vanguard Aircraft very generously provided by the British Aircraft Corporation, a party of

In the Lecture Theatre—Dr. Stever, Professor von Kármán, Sir Owen Jones and Professor Collar.

On the Platform at the opening of the Technical Sessions from left to right, Dr. H. Guyford Stever, President I.A.S. Sir Owen Jones, H. C. Luttman, Secretary C.A.I. and S. Paul Johnston, Director I.A.S.

American and Canadian delegates departed from Wisley Aerodrome. After depositing half the party at A. V. Roe and Company's aerodrome at Woodford the aircraft went on to English Electric Aviation at Warton where a tour of the research and development facilities was made, followed by a visit to the company's factories at Accrington and Samlesbury. The party at Woodford had meantime spent the morning in visiting the assembly lines and research and development departments. This party then went on to the Jodrell Bank Experimental Establishment to view the Radio Telescope and associated equipment.

On 5th and 6th September delegates visited the S.B.A.C. Flying Display and Exhibition at Farnborough. The hospitality of many firms, both in the aircraft and accessory industries, made it possible to provide almost all American and Canadian delegates with invitations to lunch.

On 7th September two visits were made. One party went to the de Havilland Engine Company's showroom and factories at Leavesden, and then on to the engine test beds and Halford Laboratory at Hatfield. The other party visited the National Physical Laboratory and spent the morning in the Aerodynamics Division. After lunch these delegates visited the Laboratory's Ship Testing Facilities at Feltham. On the evening of 7th September, some delegates were privileged to be present at the Society of British Aircraft Constructors' Dinner at the Dorchester Hotel.

On Friday, 8th September those delegates who had elected to visit Westland Aircraft Ltd. were collected by car from their hotels almost at crack of dawn. A four-hour drive brought them to the company's works at Yeovil where tours were made of the development test bays, flight sheds, erection shop and other departments of the works. The alternative visit was to Handley Page Ltd. at Radlett and Cricklewood. At Radlett delegates were briefed on the H.P.115 and 117; they saw a demonstration of fly removal techniques and examined an experimental suction aerofoil. In the afternoon the visitors saw the Victor production lines and then travelled to the company's factory at Cricklewood.

While delegates were on "field trips" and attending the technical sessions, a full programme was arranged for the ladies. This began with a luncheon party in the

Delegates being welcomed by Viscount Caldecote at English Electric.

Lecture Theatre on Monday, 4th September, followed by a short coach tour of London and a theatre in the evening. Plenty of free days were allowed for the ladies and Commitee Room 2 at the Society was an information centre and lounge for them throughout the Conference.

Among the tours arranged during the two weeks was one of Windsor Castle which was followed by a very pleasant tea party given by Lady Jones at Hillingdon; a tour of Kent including a visit to Penshurst Place; a tour of Oxford and its Colleges; the Tower of London and then, with the delegates, a river cruise and tour of the Royal Docks; and a visit to the Houses of Parliament. Some 120 wives of delegates and their children—about 40 Americans and Canadians—enjoyed these tours.

Technical Sessions

The Technical Sessions began at 9 a.m. on Monday, 11th September, and from then until the concluding remarks at 5.30 p.m. on Thursday, 14th September, 4 Hamilton Place was crowded from 8.30 a.m. every morning. Technically this Eighth Conference was considered to be one of the best of recent years. Certainly the Lecture Theatre was full for each session and there was always a number of delegates in the "overflow" rooms—the foyer and the Council Room—following their preprints and listening to the loudspeakers.

There was every opportunity for informal discussion outside the technical sessions also. Lunch was served each day for delegates in the Library and on the roof of the Lecture Theatre—mercifully the weather was good except for one day. Somewhat startling innovations—for the Society—were automatic tea, coffee, milk, candy and cigarette machines installed in the Council Room, the Library and elsewhere. The hospitable tea and coffee machines were kept busy and delegates were able, in this way, to get refreshments quickly during the morning and afternoon.

Although not officially part of the Conference the Wilbur Wright Memorial Lecture was given during the Conference, on the night of Tuesday 12th September, and was followed by a reception.

An innovation this year and a welcome break during the technical sessions was a joint tour for delegates and their ladies. This tour, one of the most popular events of the Conference, was, unfortunately, the one day on which the weather was bad. The Technical Sessions finished at 1.00 p.m. on Wednesday, 13th September, and delegates then joined the Ladies on board steamers at Westminster Bridge for a tour of the Royal Docks and a river cruise. In spite of rain and a cold wind everyone seemed to enjoy the occasion. The final event of the conference was the Dinner-Dance held at The Dorchester on Thursday 14th September.

The following puts on record the technical sessions of the Eighth Anglo-American Aeronautical Conference:

In the machine shop at the de Havilland Engine Co. Ltd. In the group are Raymond W. Young, S. Paul Johnston and M. S. Harned.

Examining wind tunnel models at A. V. Roe & Co. Ltd.—left to right, C. H. Colvin, R. R. Dexter, T. P. Wright and in the right-hand corner Dr. H. Guyford Stever.

On the River, S. Paul Johnston with Mrs. Stever.

Left to right, B. S. Shenstone, A. C. Campbell Orde, B. E. Stephenson, E. R. Sperry and R. Rypinski.

MONDAY 11th SEPTEMBER

Morning Sessions

9.15 a.m.-10.30 a.m.

Chairman: Sir George Gardner, Controller of Aircraft, Ministry of Aviation.

METEOROLOGICAL MEASUREMENTS FROM THE TIROS SATELLITES

W. G. Stroud, Chief, Aeronomy and Meteorology Division, Manager, Goddard Space Flight Center, N.A.S.A.

11.00 a.m.-12.30 p.m.

Chairman: Charles H. Colvin, President, Colvin Laboratories, Inc.

ON THE ATTITUDE CONTROL OF EARTH SATELLITES

E. G. C. Burt, Head of Dynamic Analysis Division, Guided Weapons Department, Royal Aircraft Establishment, Farnborough.

Afternoon Sessions

Chairman: Dr. Abe Silverstein, Director of Space Flight Programs, N.A.S.A.

UPPER ATMOSPHERE EXPERIMENTS WITH PARTICULAR REFERENCE TO BLACK KNIGHT AND SKYLARK

Professor Sir Harrie Massey, Quain Professor of Physics, University College, London.

4.00 p.m.-5.30 p.m.

Chairman: Professor A. R. Collar, Sir George White, Professor of Aeronautical Engineering, University of Bristol.

ADVANCEMENT IN SPACECRAFT TECHNOLOGY

Dr. George E. Mueller, Vice-President for Space Systems Program Management, Space Technology Laboratories, Inc. (Read by Mr. Rypinski.)

TUESDAY 12th SEPTEMBER

Morning Sessions

9.00 a.m.-10.30 a.m.

Chairman: D. Keith-Lucas, Technical Director, Short Brothers & Harland Ltd.

With the ladies at Windsor Castle and on the right, in Lady Jones's Garden, from left to right, Mrs. A. M. Ballantyne, Mrs. Woodall and Mrs. S. P. Johnston.

GROUND PROXIMITY EFFECTS ASSOCIATED WITH V/STOL AIRCRAFT

John P. Campbell, Head of the Dynamic Stability Branch, Langley Research Center, National Aeronautics and Space Administration.

11.00 a.m.-12.30 p.m.

Chairman: Dr. E. S. Moult, Technical Director, The de Havilland Engine Co. Ltd.

SOME CONSIDERATIONS IN SELECTING VTOL PROPULSION SYSTEMS

Arthur P. Adamson, Manager VTOL Operation, Flight Propulsion Laboratory Department. David Cochran, General Manager, Flight Propulsion Laboratory Department, Flight Propulsion Division, General Electric Co.

Afternoon Sessions

2.00 p.m.-3.30 p.m.

Chairman: Raymond W. Young, Director, Advanced Planning, Reaction Motors Division, Thiokol Chemical Corporation.

THE INVERTED TURBOJET

D. L. Mordell, Dean of the Faculty of Engineering, F. W. Eyre, Department of Mechanical Engineering, A. V. Sreenath, Assistant Professor of the Department of I.C. Engineering, Indian Institute of Science, Bangalore and attached to the Mechanical Engineering Department, all of McGill University.

4.00 p.m.-5.30 p.m.

Chairman: R. D. Hiscocks, Chief Engineer, de Havilland Aircraft of Canada.

AERODYNAMIC AND PROPULSION CONSIDERATIONS OF MINIMUM-FIELD AIRCRAFT

P. L. Sutcliffe, Chief Technician, Advanced Projects Group, V. K. Merrick, Assistant Chief Technician, Advanced Projects Group, both of Hawker Siddeley Ltd. and A. R. Howell, Senior Principal Scientific Officer in charge of Aerodynamics Department, National Gas Turbine Establishment.

WEDNESDAY 13th SEPTEMBER

9.00 a.m.-10.15 a.m.

Chairman: Air Commodore W. P. Gouin, President, Canadian Aeronautical Institute.

TRANSPORTS OF THE FUTURE—A SYSTEMS APPROACH

Harold D. Hoekstra, Chief, Aeronautics Branch, Systems Engineering Division. George C. Prill, Director, Bureau of Flight Standards, both of the Federal Aviation Agency.

10.30 a.m.-11.45 p.m.

Chairman: William Littlewood, Vice-President—Equipment and Airlines Inc., Research, American.

THE INFLUENCE OF SOME OPERATIONAL PROBLEMS ON SUPERSONIC AIR TRANSPORT

R. G. Thorne, Senior Principal Scientific Officer in charge of the Human Engineering Division of the Mechanical Engineering Department, Royal Aircraft Establishment.

11.45 a.m.-1.00 p.m.

Chairman: Sir George Edwards, Executive Director, British Aircraft Corporation.

On the left Mr. H. C. Luttman and centre Air Cdre. Gouin, President C.A.I.

THE SUPERSONIC COMMERCIAL AIR TRANSPORT—REQUIREMENTS AND PROBLEMS

John Stack, Assistant Director, Langley Research Center, N.A.S.A.

THURSDAY 14th SEPTEMBER

Morning Sessions

9.00 a.m.-10.30 a.m.

Chairman: Charles Tilgner, Jnr., Director of Professional Activities, Grumman Aircraft Engineering Corporation.

GENERAL ASPECTS OF SUPERSONIC TRANSPORT AIRCRAFT

Dr. A. E. Russell, Director and Chief Engineer, Bristol Aircraft Ltd.

11.00 a.m.-12.30 p.m.

Chairman: B. S. Shenstone, Chief Engineer, British European Airways.

ON THE NATURE OF AEROFOIL CHARACTERISTICS WITH A SINK LOCATED IN THE UPPER SURFACE—COMPARISON OF THEORY WITH SOME FAN-IN-WING EXPERIMENTS

D. C. Whittley, Assistant Chief Aerodynamicist, J. R. Bissell, Aerodynamic Department, both of Avro Aircraft Ltd., Ontario.

Afternoon Sessions

2.00 p.m.-3.30 p.m.

Chairman: Sir Arnold Hall, Managing Director, Bristol Siddeley Engines Ltd.

LOOKING AHEAD IN V/STOL

George S. Schairer, Vice-President, Research and Development, Boeing Company.

4.00 p.m.-5.30 p.m.

Chairman: Dr. T. P. Wright, Chairman of Board of Directors, Cornell Aeronautical Laboratory, Inc.

CONTROL OF VTOL AIRCRAFT

J. J. Foody, Head of the Analytical Department, Short Brothers & Harland Ltd.

Preston was the 19th Branch of the Society to be formed, in 1947.

THE BRANCHES

In the files of the Society at 4 Hamilton Place, rests a letter of some historical significance. It is written on a letterhead of the English Electric Company Limited, as from the Aircraft Division, and reads:—

19th March 1947.

"Dear Captain Pritchard,

Now that we are fairly well established in this part of the world some of us believe that it would be an excellent thing to have a Branch of the Society in Preston. Apart from ourselves there are a number of firms associated with aircraft in the district and I am sure that we should have enthusiastic support.

I hope to be in London on the 1st April for an A.R.C. meeting and I should be glad of the opportunity to discuss this with you and to know whether the Society would give me its blessing and support.

With kind regards,

Yours sincerely, D. L. ELLIS.

Written across the letter in bold blue letters is the legend "FILE PRESTON BRANCH," so presumably there was no hesitation on Captain Pritchard's part. Later, he even lectured them on "Bird Flight."

The formal application was made in July, and an order for 250 letters in August, together with the announcement of the Committee as Messrs. Petter as Chairman, D. B. Smith as Secretary, Pringle as Treasurer, together with Ellis, Page, King, Taylor and Woodford. Membership was already over 60 and said to be increasing daily—by March 1948, it was 244!

The lecture programme began in September, and the first name was that of the Director General of Long Term Planning and Projects, Ministry of Civil Aviation. His subject—"Aviation—Present and Future."

Just before compiling these notes, your scribe happened to watch the T.V. News, which included a film item of Mr. Duncan Sandys stepping out of a *manned* aircraft which brought him home from Ghana—strange to tell, it was an English Electric Canberra. Perhaps a little bird (a "Wren," maybe) would refer to Mr. Masefield's lecture of 1947.

Incidentally, the lecture programme names the President as Sir George Nelson, who, as Lord Nelson of Stafford, so remains to this day, and the Branch acknowledge to him and to English Electric the great help they have given.

In September 1948, the Branch organised a most successful exhibition at the Harris Museum and Library in Preston, being designed to show the development of aeronautics. Many of the earlier items were historical papers and prints loaned from the Hodgson Cuthbert Collection of the Society, while later years were portrayed by aircraft and engine models of the Society and those lent by aircraft firms. That this enterprise was successful is proved by attendance figures of some 4,000 in the nine days of the Exhibition.

Partly due to the pressure of work on Members in connection with the re-armament programme, numbers began to fall between 1949 and 1951, from over 200 down to 107. From then onwards a steady rise was experienced, to reach 151 in 1952/53. Today the membership is 365, of whom 100 are Main Society Members.

In tracing the history of Branches, your scribe has already commented on the semantic problems of similar names. Here, the correspondence is complicated in that D. B. Smith was Secretary of Preston Branch, while D. C. Smith was Assistant Secretary of the Society, and the exchange of letters is an example of promptness to Secretaries who may have doubts on their own record.

Mr. D. B. Smith continued as Secretary of the Branch from its inception in 1947 until 1951, when the post was taken over by Mr. J. C. King, an original member of Committee.

The English Electric Aircraft works being in Preston, and the Design and Development Centre at Warton Aerodrome, the Branch has made a practice of electing its Chairman alternatively from the two establishments.

Preston has, perhaps, an unusual record in the Society in the number of Joint Lectures held with other professional bodies. These include the Institute of Welding, the Institute of Electrical Engineers and to bring aviation to earth, with the English Electric Motor Club. Further joint lectures are planned.

Other enterprises were to follow on Brough with a special lecture on the Boeing 707 in 1959, Mr. J. Sulter flying especially from the U.S.A.; to show complete impartiality, Mr. Weiss, of Douglas, was invited to Preston in 1960 to speak on the DC-8, and a Frenchman is now in view for a lecture.

This unprejudiced view on the big aeroplane is reflected in an old programme of 1948-49, listing lectures on the "Brabazon I" and "Design Problems of Large Flying Boats."

Allied to the lecture programme, a fascinating insight into the interests of a Branch may be found in their visits. Preston seeks a wide horizon, including Power Stations, an Air Traffic Control Centre, the Manchester Ship Canal, Calder Hall Atomic Energy Establishment, and industries making music machines, diesel engines, and cold drink vending machines. Your scribe also notes some heated letters on the subject of not being able to go down a coal mine!

The Third Branches Conference at a Branch was at Preston and although a long way for most Chairmen and Secretaries, was attended by a representative from almost every Society Branch. The Branch and English Electric were wonderful hosts, and this was the first appearance of Air Marshal Sir Owen Jones as President of the Society (*see* the JOURNAL for June 1961).

In 1954 Mr. King resigned as Secretary, and was followed by Mr. E. Loveless who held this office until 1957, when J. H. Grout took over. On Mr. Petter's retirement from English Electric, Mr. Ellis (who wrote the first letter) became Chairman and continued until 1955, succeeded by Mr. W. Harpley.

Mr. Toll became Secretary in 1959, with Mr. Loveless as Chairman, this office now being served by Mr. T. O. Williams.

As this short history began with a letter, perhaps it may so appropriately end. It is dated 1955, and is from Mr. N. E. Rowe, then Chairman of the Branches Committee, to the Preston Branch:—

"It is encouraging to know that one's visits are appreciated. I greatly enjoyed the occasion and offer my congratulations to you and the Committee on the excellent organisation."

BRANCH NEWS

Belfast, like Weybridge (see this page in September JOURNAL) also sent a delegate to the Anglo-American Aeronautical Conference in September. Belfast searched its attendance sheets and records to find their most enthusiastic and most consistent young attender at Lectures and Branch affairs and the winner—an assistant lecturer at Queen's University—had all expenses at the Conference paid from Branch funds.

Luton has arranged a Schools Lecture for 13th December which is to be given in the Luton Technical School. Mr. F. W. Buglass is to talk on "How an Aircraft is Built."

Luton also has a new idea for Branch outings, a trip to Paris or some other city. If members of the Branch support the enterprise no doubt it will be one of the highlights of 1962 Branch news.

On the 19th October a lecture entitled "The Development of Visual Landing for Flight Simulators" was delivered to the **Halton** Branch, at the works of General Precision Systems Ltd. by Mr. G. M. Hellings, M.A., A.F.R.Ae.S., Chief Scientist of the Company. The large audience included Air Commodore B. Robinson, Commandant, Royal Air Force Halton and Vice-President of the Halton Branch, and Group Captain R. C. Fordham, Assistant Commandant and Chairman of the Branch. Many other Society branches were represented.

A cine film was displayed showing the "pilot's eye view" from the simulator during approaches, landings and take-offs from a typical runway at London Airport under conditions of night, full daylight, and minimum visibility with fog patches on the runway. The film ended with some light hearted low flying which evoked some apprehension from pilots in the audience.

Gloucester and Cheltenham Branch had an interesting lecture in September when Mr. R. Tyler, Chief Project Engineer of Dowty Fuel Systems Ltd., started the new session with a talk on "Impressions of the Soviet Union" in the Wheatstone Hall, Gloucester. Mr. Tyler represented his firm at the international conference on automation held in Moscow in 1960. Members of the conference were given a lavish banquet at the Kremlin and the opportunity of visiting many places of interest and factories in both Moscow and Kiev. Mr. Tyler showed a number of excellent coloured slides.—G.W.W.

Graduates' and Students' Section

CLUB AND LIGHT AIRCRAFT

The Section's first lecture of the session took place on 23rd October when Mr. David Ogilvy spoke on "Club and Light Aircraft". Before the lecture commenced two short films on light aircraft were shown by Mr. Ranald Porteous.

Mr. Ogilvy opened his lecture by saying that he intended to outline his personal specification for an ideal club and school training aircraft. This was a subject of some concern at the present time, with the Chipmunk nearing the end of its useful life, and no other type in existence that came so near to his specification.

The aircraft, being a trainer, must have two seats and one engine. Side-by-side seating seemed to be essential, because of the advantages for pilot training, avoiding unnecessary duplication of instruments, and improving instrument serviceability. Radio and instruments were the most usual failures in aircraft, so that serviceability could be an important feature in maintaining good utilisation.

A low wing seemed to be the best compromise on counts of visibility, serviceability and "crashability". The undercarriage should take all landing loads, and be easily replaceable. The legs should be "write-offs" in severe incidents to avoid transmitting loads to the wing spar or the fuselage. Whether there should be a nose-wheel or a tail-wheel was a debatable point, and the ideal solution would be the provision of either to order.

The structure must be robust. Tubular steel framework had a long life, and fabric covering of the wings and tail would give ease and rapidity of repair after mishandling or accidents. The surface area for which no repair kit was available should be kept to a minimum. How often one saw aircraft with dents in the wing leading edge skin that were there for the remainder of the aeroplane's life!

It was better to over-power a training aircraft than under-power it. A 150 h.p. engine was needed for operation from small fields, recovery from marginal situations, and obtaining aerobatic height in a reasonable time. Less maintenance should be required as the more powerful engine would be used at lower throttle, and this should help to offset the increased fuel consumption.

A trainer should be easy to fly, but should need skill to fly it accurately, in order to show up the pupil's faults. It must be fully aerobatic and spinnable with a clearly defined stall, rather than a soggy stall indicated by warning devices. While the motor car type of "drive-up, drive-down" aeroplane was sufficient for flying from "A" to "B", a few vices were essential in a training aircraft. A good maxim, the lecturer thought, was that the aircraft should be dangerous enough to frighten the pupil, but not dangerous enough to kill him!

The equipment supplied as standard should not be too basic. Students should be introduced to instruments from the very beginning of their training, and the same aircraft would be available for advanced work. As for the radio equipment, he thought that a four-channel VHF set would be a reasonable compromise, but that it should be possible to fit comprehensive equipment if desired. Flaps that really worked and efficient brakes were also essential.

The most important aspect from the point of view of a training school was serviceability. Five take-offs and landings an hour, a breakfast-to-lunch time duration, and ten to fifteen years life were required. An aircraft had to fly a thousand hours a year to earn its keep, and this points to a rugged, heavier aircraft with a more powerful engine. All parts must be easily changeable and as far as possible repairable in site workshops. All parts must be held in stock by the manufacturers at all times. Most parts seemed to have a life limit these days, and this often determined the economic life of the aircraft itself. It should be possible to give many parts unlimited life and the remainder a common life so that they could all be changed at Check V or so, all major replacements being done at one go.

Many of the non-military aircraft flying today were twin-engined luxurious machines that cost a lot of someone else's money, and were quite unsuitable for flying training. The clubs, flying schools, University Air Squadrons, Commonwealth Police Forces and others were looking for a machine with the sort of specification the speaker had outlined, and if the cost could be kept below £4,000, there was a large market for somebody. Here was scope for bright young designers!—M.L.

READER'S LETTER

Dear Sir,

I was interested to read the letter by "W.G.W." in the Graduates' and Students' page of the September 1961 JOURNAL concerning Graduate Training.

During my five-year student apprenticeship at the R.A.E., I spent some time thinking about this matter, and I should like to add some of my own experiences to W.G.W.'s very wise comments. My course was a two-monthly cycled sandwich, for the first three years in the workshops and the last two years in technical departments, largely of my own choice.

It is my belief that the flexibility of this scheme was of vast value, giving the widest opportunity for the individual to develop his own talents. Added to the practical training was a college education offering many different courses which the student could follow, according to his interests as well as his abilities! In my entry of about thirty young men, with initially very similar interests, the final specialisations were as varied as electronics, aerodynamics, production engineering and metallurgy, as well as a few who specialised in non-technical work after their apprenticeships. Only one person actually failed the course. The others came out at various levels of achievement, which is a more flexible system than the "go" or "no-go" methods at a University.

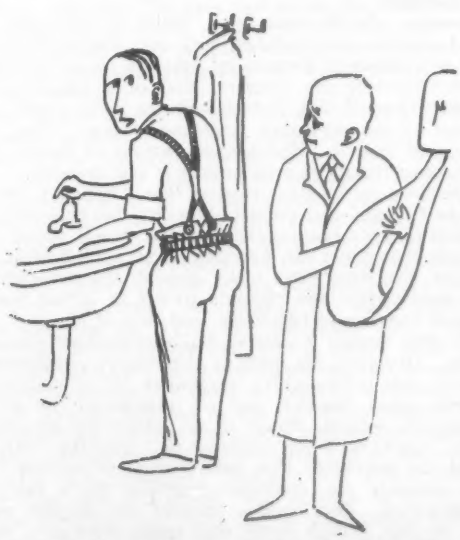
The status of factory-type apprenticeships is low among technical educations, and what a pity this is! There are innumerable apprenticeship schemes available, all as different from each other as they are from the formal University course, and most of them offering the choice of what to study, how to study it, or whether or not to study. I think that the apprenticeship is best for a good general education, and as such has great value.

Yours, etc.,

RUSSELL SAVERBY,
Flying Officer,
Grad.R.Ae.S.

Officers' Mess,
R.A.F., Luqa,
Malta.

The Next Lecture is on
24th January 1962 at 7 p.m.
"THE NEW BLUEBIRD"
by K. W. Norris



If "fail safe" is good enough for the firm, *it's good enough for me*!

THE LIBRARY

Reviews

LONG-RANGE BALLISTIC MISSILES. *Eric Burgess. Chapman & Hall, London,* 1961. 255 *pp. Illustrated.* 35*s.*

THE CONQUEST OF SPACE. *Albert Ducrocq. Putnam, London,* 1961. 300 *pp. Diagrams.* 30*s.*

ATLAS OF THE OTHER SIDE OF THE MOON. *Edited by N. P. Barabashov, A. A. Mikhailov and Yu. N. Lipskiy (for Academy of Science of the U.S.S.R.). Pergamon, London,* 1961. 171 *pp. Illustrated.* 50*s.*

SCIENCE IN SPACE. *Edited by Lloyd V. Berkner and Hugh Odishaw. McGraw-Hill, London,* 1961. 458 *pp. Illustrated.* 54*s.* 6*d.*

Publishers continue to launch books on missiles and space with almost the same frequency as the large rockets rise from their pads in the U.S.A. and U.S.S.R. One wonders whether they achieve a higher ratio of success to failure, measured (in the case of the books) in terms of their commercial sales; who reads them all?

Most of them are intended for the general reader, and in their case the reviewer is usually up against a fundamental difficulty. After eliminating those few books of this kind which are almost wholly good or wholly bad, there are a great many left which have some merit, in presenting a useful collection of facts, or in discussing their subject from some fresh aspect, but these are invariably not entirely reliable. For such an audience, it does not do to be unduly pedantic, but the reviewer is nevertheless soon put off by discovering some inaccuracies or half-truths about his own special subject; he knows that the author, almost always, is not a professional worker in any one of the wide range of subjects covered in his book, and is correspondingly suspicious of its general soundness.

These difficulties are exemplified by both the first two volumes listed above. Thus, Burgess tells us that a rocket jet velocity " is proportional to the temperature of the gas inside the combustion chamber and inversely proportional to the mean molecular weight of the products of combustion." The omission of a vital square root is important to an engineer, but still leaves a layman with more or less the right idea.

However, the Burgess book, which is very well illustrated, can be recommended, with only this broad reservation, as a source of general information on all the features which constitute the complex total of a ballistic missile system. In particular, it deals with the history and characteristics of the American Redstone, Jupiter, Thor, Atlas, Titan and Polaris. The use of various of these missiles as boosters for space programmes is also covered.

Ducrocq informs his readers that " boosters are rated as a half-stage," and unfairly brackets the Americans with the Russians for keeping their booster details secret, on the grounds that while the Russians never publish their all-up weights, the Americans never publish the payloads. He also implies that the ultimate trends in rocket fuels are towards boron and beryllium, and two of his illustrations imply that several American liquid-propellant rockets are solids. However, his book is not mainly concerned with vehicles, but rather with a somewhat diffuse discussion of general space research and of trajectories; he also has some quite sensible things to say about the tendency for space capability to be confined to " The Big Two," and about the possibility that development of nuclear rockets may relegate the chemical monsters to a fairly-early obsolescence. One doubts whether the English publication of this French book was really necessary, but the translation is good—though the chapter on recovery and aerodynamic re-entry phenomena is headed " Recuperation Techniques."

The second two volumes are in a quite different class from the first pair; each has the authoritative association of one of the Academies of Sciences in " The Big Two." However, it is rather unlikely that either will have much appeal to members of the R.Ae.S., simply because they are *not* general in scope.

" The Atlas of the Other Side of the Moon " has, of course, a very definite historical interest, being the record of the very first pictures ever taken of this area, by the so-called Lunik III two years ago. The photographs were taken over a period of 40 minutes, while the lunar probe was traversing that part of the Moon's surface which is always invisible from Earth; they were then transmitted back by radio, when the probe had returned to the proximity of Earth. Details of the techniques involved are given, and the volume certainly confirms that Soviet scientists have made conscientious and laborious attempts to make the most of the data so gained, though not in the sense that more is claimed than could be justified by the very indifferent quality of the pictures. A layman's reaction to this might well be to doubt whether it makes a book costing £2 10s. 0d. worthwhile! After all, we shall soon have some much better photographs of the other side of the Moon; perhaps most astronomers could restrain their natural impatience, but not the lunar specialists. For the present, it can at least be said that the back view is generally similar in character to the front, which was what was expected.

" Science in Space," edited by the Chairman and Executive Director of the Space Science Board of the U.S. National Academy of Sciences, is a highly-technical work for pure scientists. It is a collection of papers by 20 contributors (including the two editors, Urey, van Allen, Wexler, and so on) and covers fairly exhaustively the whole field of scientific research made possible by the development of vehicles which can lift instruments (and men) into this novel environment. References to technology or applications are few and far between; a plea is made for international co-operation and the prospect is welcomed of other countries, besides " The Big Two," developing space-launching capabilities in due course. A chapter (by Professor R. H. Dicke, of Princeton) on " The Nature of Gravitation " greatly interested this reviewer. Though much of it was as far over my head as the satellites which the author hopes to use for novel experiments on his subject, it still conveyed two outstanding impressions:

(*a*) this is a perfect example of the way in which space research may generate new discoveries, and

(*b*) it made clear our fundamental ignorance about this most familiar natural phenomenon—surely the most important of all to aeronautical people of all kinds!—A. V. CLEAVER.

FATIGUE TESTING AND ANALYSIS OF RESULTS. *Edited by W. Weibull. Pergamon, Oxford,* 1961. 305 *pp.* 84*s.*

This book has few illustrations and no conversations; although the older reader is likely to find it absorbing, the younger may deem it dull and seek other entry into Wonderland. Because Professor Weibull's knowledge of fatigue is encyclopaedic and in this volume, prepared for AGARD (which is a bit of NATO), he has put his wide experience at the disposal of the earnest reader. It is all put down, with nothing omitted, nothing extenuated, in so lucid and clear a style that it is difficult to believe that English is not the author's native language.

In a hundred pages symbols and nomenclature, testing methods, testing machines, instruments and measuring devices and the design, preparation, measurement and pro-

tection of test pieces are all thoroughly reviewed, with references to original sources at the end of every section. Forty pages relate to factors which may affect fatigue test results, forty more to planning of test programmes and presentation of results, and the last seventy are devoted to analysis of results.

The absence of illustrations from the first two-thirds of the volume is a pity, but the descriptive writing is so good that the lack of pictures of testing machines and such like is no great matter. Still a diagram or two would have helped and would have rescued from obscurity one or two casual victims of over-condensation. However, the really careful reader will not miss the Schenck machine.

It is in the later sections on programming and analysis that the lack of conversations is to be borne in mind. What there is to be said on the engineering aspects the author says as tersely as any and more clearly than most, so that the reader ought to reach half-way in a mood of appreciative acquiescence. Let him then beware, because the Professor is also a philosopher, and his persuasive pen may beguile the trusting reader into as dismal a philosophy as ever came out of Scandinavia. "It is believed—and this is an essential assumption—that this frequency will tend to a definite value with an increasing number of tests." Test and ever yet more tests; certainty even of the probability *P* of a "success" is always just round the corner. How much more sanguine is the outlook credited to Dr. Schvette, who tests four similar pieces, lets but one fail and then concludes that approximately 80 per cent (six) may be relied upon to survive that endurance.

This is the merit of the book as a whole, that it caters for all tastes; fatigue limit, fretting failures in 1911 in the United Kingdom and in 1924 in the U.S.A., slipping clutch in 1931, extreme value probability; Professor Weibull has them all and is not to be faulted. Only at the end he will retire into his laboratory and get down to careful conduction of repeat tests on 417 precisely similar samples. But Professor Weibull (and AGARD) delight us all by dedicating this work to the memory of Deryck Smith.—H. L. COX.

MY POLAR FLIGHTS. *Umberto Nobile. Müller, London.* 1961. 288 *pp. Illustrated.* 25*s.*

In such a long-civilised nation as the Italians, the readiness to castigate their own heroes is an extraordinary weakness. Umberto Nobile made an outstandingly enterprising and successful flight with Amundsen as observer, across the North Pole from Spitzbergen to Alaska in 1926 with the shapely semi-rigid airship Norge designed by himself; and received world-wide applause and the highest honours, including promotion to the rank of General from his grateful country. Two years later, with a similar airship called Italia, Nobile reconnoitred the north coast of Siberia in one flight, and in another flew over the Pole again. But on the way back he crashed, through a sudden heavy build-up of ice, within 80 miles of Spitzbergen, and because of this misfortune every device of the Fascists was used to ridicule his enterprise and smear his name.

After Italia's crash on the ice, the captain of the baseship Citta di Milano absolutely neglected to listen-in for S.O.S. messages with the result that the first to be picked up was by a Russian amateur—and after two weeks. The search of Norwegian, Swedish, Finnish, Russian and French aircraft that followed was a masterpiece of uncoordinated good-will and apart from supply-dropping, achieved only the rescue of Nobile himself. He was taken off by the Swedes because he was far the worst injured and they needed him to direct the otherwise incoherent rescue efforts. In the end the main body of survivors was saved by the Russian icebreaker Krassin after seven endless weeks of exposure and spirits alternately raised and dashed by the sight of circling aircraft. The difficulty of locating a tent and six men on the ice proved so great, even in good visibility, that neither the aeroplanes nor the icebreaker would ever have found the survivors had they not had a radio transmitter.

Balbo was the sworn enemy of airships and had regarded Nobile's 1926 success with jealousy. He arranged a secret investigation, hearing no evidence from Nobile, and which after a year declared that Nobile had "mismanaged the airship, causing it to crash" and was at fault in allowing himself to be rescued first. In point of fact the crash was inevitable, and although he had protested against being taken off first, the Swedes were adamant. Thus disgraced, Nobile now had to resign all his honours, and took a job building and flying airships in Russia for four years. Only in 1945, after the demise of Fascism, did another government enquiry reopen his case, exonerating him from all blame and making some financial redress.

"My Polar Flights" reveals the real and creditable truth about Umberto Nobile. His polar flying alone marks him as one of the great airship commanders of history. Here in the barren wilderness of ice which is the Arctic, Nobile pitted his frail craft against fog, and gale and snow and ice, and came within an ace of complete success. Yet when Italia foundered, he and his loyal crew stared seemingly complete disaster in the face and, almost without exception, stood their ordeal like men.—JOHN GRIERSON.

THE ACES. *Frederick Oughton. Neville Spearman, London, 1961. 390 pp. Illustrated. 30s.*

With the widespread and growing interest in the aircraft and aviation of the 1914-18 War period it is perhaps inevitable that more and more writers and publishers should try to cash in on it. This would be a good thing if all the authors tried to understand their subject and realised that, in history, there is only one truth; and one wishes that publishers would make some intelligent attempt to assess an author's competence to handle the subject before commissioning or accepting a book from him. Had that been done in the case of *The Aces* it seems doubtful whether it would have seen the light of day.

Mr. Oughton's other works are listed within this book. One turns from their titles to this work on the very different subject of air fighting in the First World War with some apprehension, and one does not have to read far before one's fears are confirmed.

The book commences with a somewhat superfluous history of the development of aircraft. As early as page 29 one is arrested by the statement "The old idea of ailerons had now been scrapped in favour of moving pieces on the mainplanes." Of the Gnome engine the reader is told that "To gain full force, the throttle had to be opened to its total capacity." These are typical examples of the many indications that the author's understanding of aircraft, flying, and their terminology is rather less than perfect.

The author claims to have drawn material from unpublished sources. That is doubtless true, but his extraordinary interpretations of the various books and documents that he lists in the impressive bibliography make it impossible to accept anything he says without making an exhaustive search for confirmation. He has for instance, swallowed *Flying Dutchman* hook, line and claptrap. He is not, of course, the first author to perpetuate errors that appear in other books, and will not be the last; but there is no excuse for implying, *e.g.* that Major C. J. Burke designed the B.E.1; that the B.E.2 (*sic*) could do 150 m.p.h.; that Gordon Bell was a fighter pilot, much less that he ever shot down six enemy aircraft in one day; that parachutes were available to German airmen in 1916; that the crashes that led to the monoplane ban of 1912 occurred during the war (the author repeatedly displays an irritating lack of sense of chronology); and so on—and on. The book was printed in Holland, but surely someone could have read the proofs well enough to avoid such errors as Roland Carros (and Garos) and Graham Gilmore. (And who on earth was Max Franz Immelmann?)

The book is mostly about aerial combat, but the author's descriptions of air fighting do not come off, owing to his unfamiliarity with flying. Parts of the narrative are

somewhat reminiscent of the cornier efforts of pre-1914 non-technical journalists, and as one reads one develops a growing expectation of finding, sooner or later, the equivalent of "With one bound, brave Jack was free." One would greatly like to see "a planes (*sic*) which attacked downwards *and backwards*," (page 83).

The informed reader can, if he is so minded, have an amusing time counting up the multitudinous errors; and his amusement will expand to hilarity when he reaches the illustrations and their astonishing captions. Author and publisher are hereby challenged to prove that any Clerget-powered Sopwith Triplane had a variable-pitch airscrew (the proof should include a definition of a variable-pitch airscrew); that the picture alleged to be Beauchamp-Proctor is anyone but Lufbery, and that B-P was killed at Hendon; that Warneford lost his life when the Zeppelin he attacked exploded (this should be compared with page 148); that Fokker invented a device to enable guns to "shoot through synchronised propellors"; that any Spad S.7 had a 110-h.p. Clerget engine; that the Martinsyde F.1 was a B.E.2c . . .

One would like to be able to find a word of praise for something in this book, but it is so woefully—and needlessly—inaccurate, its shortcomings so painfully obvious, that it is difficult to do so. Regretfully, one concludes that *The Aces* is an unnecessary book.—J. M. BRUCE.

THE FORGOTTEN ONES, THE STORY OF THE GROUND CREWS. *Air Chief Marshal Sir Philip Joubert de la Ferté, K.C.B., C.M.G., D.S.O. Hutchinson, London,* 1961. 255 *pp. Illustrated. Index.* 25*s.*

For the first time, here is a review of the work of the ground crews, the airmen and airwomen of both World Wars who contributed so much to the defeat of the King's enemies. Anyone who heard the Wartime broadcasts by Sir Philip Joubert de la Ferté, or who has read any of his writings will know that he is a first-class public relations man and a very readable author. His latest book is written with great understanding and humanity. His keen observation and remarkable memory combined with the useful liaison which he has maintained with retired airmen and officers have enabled him to tell a fascinating story.

Any author would be hard-put to write a book on the story of the airman in two World Wars which is at the same interesting and chronologically exact. This book is, in fact, a character study as well as a history; a study of the transformation of soldiers and seamen into airmen when the Royal Flying Corps was formed and of the build-up of "esprit de corps" in units of very mixed origin under the baleful eyes of senior N.C.O's of the Brigade of Guards. The grim conditions existing on the Western Front endured by men who had little hope of returning to homes they knew to be fairly safe from the risks of war may be compared with the Hitler war. In that, although the airmen's billets were sometimes far better, in other ways their lot was harder, working round the clock in arctic or tropical conditions in order to keep the aircraft flying and the supplies moving; unhappily for many of them, there was also the anxiety for their homes and families under repeated enemy attack. The reader is able to draw his own conclusions on the inevitable and unchanging good humour and courage of the "erk." If the First War demanded courage, the Second also required a steady nerve as well and, in this respect, the air women showed up particularly well.

Sir Philip's study is full of humour and will be a joy to anyone who served both in the ranks and also as an officer. The reader may not have known the individuals about whom the author tells so many amusing and ironic stories but his memory may be jogged into recalling, perhaps with pleasure, perhaps without, similar characters.

Perhaps the strongest impression of all will be of the author's tolerance and understanding of the nature of his fellow men and women, whether equals or subordinates—a very kindly person.—A.S.C.L.

WINGS ON MY SLEEVE. *Capt. Eric Brown, O.B.E., D.Sc., A.F.C., R.N. Arthur Barker, London,* 1961. 191 *pp. Illustrated.* 21*s.*

This is a Test Pilot's story with a difference. For although many books have been written since the war recounting the experiences of famous Test Pilots, they have each been confined to a relatively limited field, imposed usually by the specialisation associated with a particular aircraft manufacturer. Captain Brown, by contrast, had the unique experience of spending six years as a Test Pilot at the R.A.E., three of them in command of the Aerodynamics Flight, as well as periods at Boscombe Down and at Patuxent in the U.S.A. This meant that during his test career he carried out experiments on almost every conceivable type of flying machine, including some highly experimental research aircraft, as well as on an astonishing variety of Fighters, Bombers, Naval Aircraft, Transport Aircraft and Helicopters. All this occurred moreover, during a period which many regard as the most exciting in the history of aviation, covering the pioneering days of jet flight and the first probings into transonic speeds.

Inevitably therefore, he has a fascinating story to tell and he tells it in a vivid forthright style, communicating the curious conjugation of adventure and scientific approach which is an essential feature of all true test flying. The book includes some extremely interesting first-hand accounts of some outstanding highlights of aviation history, particularly the first landings ever to be made by a jet aircraft on a Carrier, and the development at the R.A.E. of the technique of landing an undercarriageless aircraft on a flexible pad. The chapters on his Service career outside the test flying period, although perhaps slightly more conventional, are no less exciting, and it seems hardly credible that one man should have survived the countless incidents which he relates with obvious enthusiasm but without embellishment, as those who have shared some of the experiences with him, well know.

There are some very minor inaccuracies in his recollections of the technical background to some of the experiments in which he took such a distinguished part, but these are of little importance compared with the value to be obtained from this account of what must have been the most varied of all test flying careers.—HANDEL DAVIES.

BEYOND THE PLANET EARTH. *Konstantin Tsiolkovsky. Translated from the Russian by Kenneth Syers. Pergamon Press, London. 1960. 190 pp. 15s.*

In the light of present knowledge, this is an incredibly ingenious and accurate forecast of the problems being faced and overcome in 1961 in preparing man for interplanetary flight. Detail inaccuracies occur of course, but it must be remembered that the book is based on Tsiolkovsky's work *The Probing of Space by means of Jet-Devices* published in 1903, and that this book was published in Russia in 1920.

Tsiolkovsky was born in 1857 and is regarded as the father of Soviet Space Travel. His foresight compares with H. G. Wells and Jules Verne although his approach has been described as more reasoned than either of theirs. As early as 1883 he published a work outlining a space vehicle powered on the jet principle. His grasp of the problems of space travel and space survival is astonishing.

And so to his fantasy, a story set among the peaks of the Himalayas; six disillusioned and morally-shattered men live in a castle high in the mountains, a Frenchman Laplace, a German Helmholtz, a Russian Ivanov, an Englishman Newton, an Italian Galileo and an American Franklin.

These men, driven to seclusion by disillusionment with people and the pleasures of life, devise a space ship driven by a rocket powered by two "progressive explosion liquids" in which, together, they explore space and prepare for the colonisation of the space between earth and moon. This is an enthralling book and those without technical attainments in astronautics will enjoy it since it is written as a guide to the layman by a true prophet, honoured as such in his own country.—A.S.C.L.

Additions to the Library

Aeronautics: Discussions held at the Aeronautic Production Forum at Los Angeles, California, Oct. 10-11. Society of Automotive Engineers, New York. S.A.E. S.P.-333. 1960. 99 pp.

Aerospace Manufacturing Engineering Forum 1960. Society of Automotive Engineers, New York. S.A.E. S.P.-331. 1960. 22 pp.

Aircraft Optimization. K. L. Sanders. S.A.W.E. 20th National Conference, May 1961. Technical Paper No. 289. 53 pp.

Anti-Friction Bearings Seminar. Society of Automotive Engineers, New York. S.A.E. S.P.-168. 1960. Approximately 70 pp. Illustrated. No price quoted.

Applications and Limitations of New Developments in Metals Joining Processes. P. J. Rieppel. Society of Automotive Engineers, New York. S.A.E. S.P.-173. 1960. 18 pp.

Aviation Electronics Technician 1 & C. U.S. Bureau of Naval Personnel, Washington. U.S.G.P.O. 1961. 555 pp. 27s.

The B-58 Reliability Program. Society of Automotive Engineers, New York. S.A.E. S.P.-183. 1960. 99 pp. Illustrated.

Mechanical Prestressing. Summary of Reports Presented at the 1960 Biennial Meeting, S.A.E. I.S.T.C., Division 20, on Mechanical Prestressing of Metals, May 16-18 1960. Society of Automotive Engineers, New York. S.A.E. S.P.-181. 1960. 17 pp.

Missiles and Ventures into Space, 1960-1961 Report. U.S. Department of the Army, Washington. Headquarters, Department of the Army. 1961. 73 pp. 9s.

Proceedings of a Conference on Results of the First U.S. Manned Suborbital Space Flight. U.S.G.P.O. 1961. 76 pp. Illustrated. 50 cents. A conference held by N.A.S.A. and two other bodies on 6th June. Three papers on the Mercury Programme, three on biomedical data and three on pilot performance. Obtainable through H.M.S.O.

Radio Astronomy. J. H. Piddington. Hutchinson, London. 1961. 125 pp. Illustrated. 12s. 6d. Written in the Radiophysics Laboratory of the Commonwealth Scientific and Industrial Research Organization in Sydney, this is an authoritative introduction to the techniques and applications of radio astronomy, including radar astronomy and radio waves from the moon, planets, rockets and satellites. Intended for the reader with little scientific training; descriptions are simplified and mathematical processes kept to a minimum.

Stephen Morris. Nevil Shute. Heinemann, London. 1961. 273 pp. 16s. Two hitherto unpublished short novels written in the 1920s and now published under the one title because the central character and one or two others of the first story appear also in the second. Both good flying stories they obviously contain glimpses of the author's own experiences. The first story gives a picture of joy riding and the struggles of aircraft firms in the immediate years after the 1914-18 War and the second, an account of preparations for an early commercial Atlantic flight. Light reading, perhaps not Nevil Shute at his best but very readable and with an authenticity which will revive memories for many concerned with flying in the twenties and early thirties.

Theoretical and Experimental Analysis of Members Made of Materials that Creep. O. M. Sidebottom, *et al.* University of Illinois, Bulletin 460, Urbana, 111. Consists of an Introduction, Theory, Materials and Methods of Testing and Discussion of Results. 23 references are appended.

They Got Back. The Best Escape Stories from the *R.A.F. Flying Review*. Herbert Jenkins, London. 1961. 143 pp. Illustrated. 12s. 6d. Ten stories selected from a series which appeared in this monthly journal. If one skips the journalese "atmosphere" the stories in themselves are gripping.

The Wright Brothers. Geoffrey Norris. Burke, London. 1961. 159 pp. Illustrated. 10s. 6d. One in a series entitled "People, Places and Things" in which "fact is dramatised for the young reader." The book is not entirely Wright Bros. but much background is provided, touching on Cayley, Chanute, and others.

Where No Birds Fly. Philip Wills. Newnes, London. 1961. 141 pp. Illustrated. 21s. This book is a mixture—brief notes on technical and semi-scientific aspects of the sport of gliding, Appendices giving lists of gliding clubs, overseas organisations, world records and British records and recommended reading covering most aspects of gliding, but this is barely one quarter of the whole. Mainly the book is autobiographical, of some of the author's flights and adventures, successes and near misses in the United Kingdom, Europe, New Zealand and the U.S.A. and of his Team of which the most important member is his wife who has towed glider trailers over 150,000 miles of roads all over the world, always " retrieving " her man—frequently by an almost magical telepathy of knowing where to look for him. Philip Wills knows as much about gliding and soaring as anyone anywhere; he writes easily, amusingly and modestly and above all he has tremendous enthusiasm. He conveys the excitement, the anxieties, and the shear beauty and magic of soaring flight in the waves and clouds " where no birds fly."

Reports

AERODYNAMICS

BOUNDARY LAYER *see also* INTERNAL FLOW
THERMO-AERODYNAMICS
WINGS AND AEROFOILS

Boundary layer measurements at low speed on two wings of 45° and 55° sweep. G. G. Brebner and L. A. Wyatt. C.P. 554. 1961.—(1.1.2.1 × 1.8.2.2).

An experimental study of the glancing interaction between a shock wave and a turbulent boundary layer. A. Stanbrook. C.P. 555. 1961.—(1.1.3.4 × 1.2.3.2).

Some calculations by the Crocco-Lees and other methods of interactions between shock waves and laminar boundary layers, including effects of heat transfer and suction. K. N. C. Bray et al. *C.P.* 556. 1961.—(1.1.1.4×1.1.5.4×1.2.3.2×1.9.1).

The calculation of the compressible turbulent boundary layer in an arbitrary pressure gradient—a correlation of certain previous methods. B. S. Stratford and G. S. Beaver. R. & M. 3207. 1961.—(1.1.2.2×1.1.2.3×1.1.2.4).

Calculation of the turbulent boundary layer with continuously distributed suction. W. Pechau. A.G.A.R.D. Report 259. *April* 1960.—(1.1.5.1).

Recent developments in the field of low drag boundary layer suction research. W. Pfenninger. A.G.A.R.D. Report 262. *April* 1960.—(1.1.5.1).

On the stability of Couette flow. F. Schultz-Grunow. A.G.A.R.D. Report 265. *April* 1960.
Although the Couette flow with rotating outer cylinder and stationary inner cylinder is regarded as the critical experiment in laminar boundary layer stability experiments, the stability of this flow has not yet been fully investigated. The present

Report shows that it is possible, however, to obtain an exact solution for this stability problem, and such a solution is developed.—(1.1.1.1).

Boundary layers in three dimensions. J. C. Cooke and M. G. Hall. A.G.A.R.D. Report 273. *April* 1960.—(1.1.1.2×1.1.3.1).

On surface pressure fluctuations in turbulent boundary layers. G. M. Lilley and T. H. Hodgson. A.G.A.R.D. Report 276. *April* 1960.—(1.1.3.1).

A background to the problems of wind-tunnel interference. E. W. E. Rogers. A.G.A.R.D. Report 292. *March* 1959.
The progress that has been made in the field of wind tunnel interference is briefly surveyed and some of the present-day difficulties are pointed out. In the concluding section an attempt is made to assess the direction in which future work is required.—(1.1.2.1).

The existence of three-dimensional perturbations in the re-attachment of a two-dimensional supersonic boundary layer after separation. J. J. Ginoux. A.G.A.R.D. Report 272. *April* 1960.—(1.1.4.4).

Critical survey of published theories on the mechanism of leading-edge stall. I. Tani. Aero. Res. Inst. Tokyo. Report 367. *June* 1961.—(1.1.4.1×1.10.0.1).

COMPRESSIBLE FLOW *see also* BOUNDARY LAYER
THERMO-AERODYNAMICS
TESTING AND INSTRUMENTS

Hypersonic viscous shock layer of nonequilibrium dissociating gas. P. M. Chung. N.A.S.A. T.R. R-109. 1961.
The flight regime considered is for speeds near satellite speed and for altitudes between 200,000 and 300,000 feet. The convective heat transfer to non-catalytic wall is obtained. The effects of nose radius, wall temperature, and flight altitude on the chemical state of the shock layer are studied. An analysis is made on the simultaneous effect of non-equilibrium chemical and air rarefaction on the shock layer thickness.—(1.2.3.2×1.9.1×34.4).

Charts for conical and two-dimensional oblique-shock flow parameters in helium at Mach numbers from about 1 *to* 100. *A. Henderson and D. O. Braswell. N.A.S.A. T.N. D*-819. *June* 1961.
Charts are presented for the determination of certain flow properties in the flow field and on the surface of cones and wedges at Mach numbers from about 1 to 100 in a perfect gas with a ratio of specific heats of 5/3. In addition, a table of the isentropic subsonic flow parameters is included.—(1.2.3.2).

Pressure distribution and shock shape over blunted slender cones at Mach numbers from 16 *to* 19. *C. H. Lewis. A.E.D.C.-T.N.*-61-81. *August* 1961.—(1.2.3.2×1.6.1).

Pressure distributions on a hemisphere cylinder at supersonic and hypersonic Mach numbers. A. L. Baer. A.E.D.C.-T.N.-61-96. *August* 1961.—(1.2.3.2×1.6.1).

On molecular vibrational relaxation in the flow of a chemically reacting gas. P. J. Musgrove and J. P. Appleton. A.A.S.U. Report 183. *June* 1961.
A method is presented for predicting the molecular vibrational temperature in a gas flow where the internal energy of vibration is small compared to the total internal energy of the gas. Coupling between the relaxation rate of molecular vibration and atomic recombination is neglected. A criterion is proposed which determines the position in the flow at which significant departures from vibrational equilibrium are likely to occur.—(1.2.3.1×34.4).

Ein Diagramm-Verfahren zur Beschreibung der Strömungszustände in rotationssymmetrischen Stossdiffusoren. O. Lutz et al. *D.F.L. Bericht* 138. 1961. (*In two parts text and diagrams*). (*In German*).—(1.2.3.2×1.5.1).

CONTROLS *see* STABILITY AND CONTROL
TESTING AND INSTRUMENTS

FLUID DYNAMICS *see also* INTERNAL FLOW

Theory of an electromagnetic mass accelerator for achieving hypervelocities. K. Thom and J. Norwood. N.A.S.A. T.N. D-886. *June* 1961.—(1.4.4×32.2.1).

Slip flow over a magnetized sphere moving slowly in a conducting medium. G. W. Pneuman and P. S. Lykoudis. Purdue Univ. Report A-61-1. *July* 1961.—(1.4.4).

Linearised Couette flow for arbitrary Knudsen number. D. R. Willis. K.T.H. Aero. T.N. 52. 1960.—(1.4).

INTERNAL FLOW *see also* COMPRESSIBLE FLOW
THERMO-AERODYNAMICS

Investigation of an axisymmetric internal compression inlet at a Mach number of about 3·8. *J. H. Lundell* et al. *N.A.S.A. T.N. D*-854. *June* 1961.
The design employed boundary-layer removal in the vicinity of the inflection point of the supersonic contour. Static and total pressure fluctuations were measured in the transonic region.—(1.5.1×27.1.2).

Corner interference effects. K. Gersten. A.G.A.R.D. Report 299. *March* 1959.
This Report discusses the problem of three-dimensional incompressible flow in the corner of two semi-infinite plates intersecting at right angles, with particular reference to interference effects between the boundary layers of the two plates. The influence of interference on the transition from laminar to turbulent flow is also discussed.—(1.5.1.2×1.1.1.1×1.1.3.1).

Potential flow through spiral casings. N. Athanassiadis. Inst. fur Aero. Zurich Mitt. 30. 1961. (*In English*).
An investigation has been made of the potential flow through two-dimensional and three-dimensional spiral castings. Since a purely mathematical treatment of this problem encounters nearly insurmountable difficulties, the electric analogy method was applied. The experiments were made on four spiral models (two two-dimensional and two three-dimensional).—(1.5.3×1.4.1).

Theoretische und experimentelle Untersuchungen über die Lüftungsanlagen von Strassentunneln. A. Haerter. Inst. fur Aero. Zurich Mitt. 29. 1961. (*In German*).—(1.5.1.1).

LOADS *see also* COMPRESSIBLE FLOW
STABILITY AND CONTROL
WINGS AND AEROFOILS

Application of Monte Carlo technique for determining manoeuvering loads from statistical information on airplane motions. H. A. Hamer et al. *N.A.S.A. T.N. D*-524. *May* 1961.
The flights covered altitudes up to about 50,000 feet and Mach numbers up to 1·22. The analysis was performed to determine the feasibility of calculating horizontal tail-load from data on the flight conditions and aeroplane motions. Loads were calculated by a direct approach and by a Monte Carlo technique, and were compared with the measured loads for each type of mission performed during the flight investigation.—(1.6.2×33.1.1).

Theoretical evaluation of the pressures, forces, and moments at hypersonic speeds acting on arbitrary bodies of revolution undergoing separate and combined angle-of-attack and pitching motions. K. Margolis. N.A.S.A. T.N. D-652. *June* 1961.
Equations based on Newtonian impact theory have been derived and a computational procedure developed which enables the determination of the aerodynamic forces and moments acting on arbitrary bodies of revolution with non-decreasing cross-sectional area distributions undergoing either separate or combined angle-of-attack and pitching motions. The analysis considers variations in angle-of-attack from −90° to 90° and allows for both positive and negative pitching velocities of arbitrary magnitude. The results are also directly applicable to bodies in either separate or combined sideslip and yawing manoeuvres.—(1.6.1×1.8.2.1×25.2).

Aerodynamic loads at Mach numbers from 0·70 *to* 2·22 *on an airplane model having a wing and canard of triangular plan form and either single or twin vertical tails. V. L. Peterson and G. P. Menees. N.A.S.A. T.N. D*-690. *June* 1961.
Data were obtained for angles-of-attack ranging from −4° to +16°, nominal canard deflection angles of 0° and 10°, and angles-of-sideslip of 0° and 5·3°. Selected portions of the data are presented in graphical form.—(1.6.1×33.1.1).

Pressure loads produced on a flat-plate wing by rocket jets exhausting in a spanwise direction below the wing and perpendicular to a free-stream flow of Mach number 2·0. R. A. Falanga and J. J. Janos. N.A.S.A. T.N. D-893. May 1961.
The variables involved were nozzle configuration, nozzle position beneath the wing, and pressure ratio.—(1.6.1×1.8.1.2×1.8.2.2×33.1.1×1.10.2.2).

Application of power spectral analysis methods to maneuver loads obtained on jet fighter airplanes during service operations. J. P. Mayer and H. A. Hamer. N.A.S.A. T.N. D-902. May 1961.—(1.6.2×33.1.1).

Transonic wind-tunnel investigation of the fin loads on a 1/8-scale model simulating the first stage of the Scout research vehicle. T. C. Kelly. N.A.S.A. T.N. D-918. June 1961.
Tests were conducted at Mach numbers from 0·40 to 1·20 and a Reynolds number per foot of about $3{\cdot}5\times10^6$ per foot. Results which show the effects of fin roll angle and the effects of deflecting a control which formed the tip of the delta fin are presented.—(1.6.1×1.8.1.2×33.1.1).

PERFORMANCE *see also* STABILITY AND CONTROL
AIRCRAFT OPERATION

On the representation of fan-wing characteristics in a form suitable for the analysis of transition motions, with results of tests of an aspect-ratio-1 wing with fan at 0·354 chord. N. Gregory. C.P. 552. 1961.—(1.7.1×1.10.2.2×27.1).

STABILITY AND CONTROL *see also* BOUNDARY LAYER
LOADS
WINGS AND AEROFOILS

Flight controllability limits and related human transfer functions as determined from simulator and flight tests. L. W. Taylor and R. E. Day. N.A.S.A. T.N. D-746. May 1961.—(1.8.0.1×13.2×9).

Aerodynamics of a fan-in-fuselage model. R. L. Maki and D. H. Hickey. N.A.S.A. T.N. D-789. May 1961.
A large-scale model with an unswept wing and a high disc-loading fan mounted in a fuselage duct was tested in the wind tunnel. The test results were used to study transition flight characteristics associated with the submerged fan concept.—(1.8.2.2×27.1×3.12).

Static longitudinal aerodynamic characteristics at transonic speeds of a blunted right triangular pyramidal lifting reentry configuration for angles of attack up to 110°. J. P. Mugler and W. B. Olstad. N.A.S.A. T.N. D-797. June 1961.
The Reynolds number, based on the mean geometric chord, varied during the tests from about $2{\cdot}2\times10^6$ to $5{\cdot}7\times10^6$. Comparisons are made which show the effects of longitudinal stability and performance of blunting the model nose, leading edge, and ridge line.—(1.8.2.2×3.14×8.2×25.2).

Low-speed wind-tunnel investigation of a reflection plane wing model equipped with partial-span jet-augmented flaps. J. H. Otis. N.A.S.A. T.N. D-815. May 1961.
Three 50 per cent partial-span jet-augmented flap configurations located inboard, outboard, and at the mid-semispan position were tested through a momentum coefficient range from 0 to about 10 and an angle-of-attack range from −10° to approximately 28°. The corresponding flow-field characteristics are presented for a longitudinal-tail position of 4 wing chords behind the trailing edge of the wing through a range of tail-height locations of ±2 chords.—(1.8.2.2×1.3.4).

Hovering flight investigation of two methods of controlling a man-carrying ducted-fan vehicle of the flying-platform type. L. P. Parlett. N.A.S.A. T.N. D-841. June 1961.
Tests have been performed during which men of widely varying previous flight experience served as pilots of a 4-foot-diameter vehicle, controlling it either kinesthetically or by a system of air jets actuated by an aeroplane-type control stick.—(1.8.0.1).

A flight examination of operating problems of V/STOL aircraft in STOL-type landing and approach. R. C. Innis and H. C. Quigley. N.A.S.A. T.N. D-862. June 1961.
The operating envelope of a large twin-engined STOL aircraft has been examined and general limitations have been pointed out which the pilot must consider when choosing a minimum landing approach speed for STOL aircraft. The significance of satisfactory stability and control characteristics in this regard is discussed. The problems reviewed in the report would also be representative of those of a large, overloaded V/STOL aircraft operating in an STOL manner.—(1.8.1.2×1.8.2.2×5×3.12).

Aerodynamic characteristics of a four-propeller tilt-wing VTOL model with twin vertical tails, including effects of ground proximity. K. J. Grunwald. N.A.S.A. T.N. D-901. June 1961.
The tests covered three general configurations: a pure tilt wing; a tilt wing with flap, slats, and wing-span extension; and a tilt wing with speed brakes and slats. These tests were conducted in and out of ground effect and included investigation of stabiliser and tail-fan effectiveness.—(1.8.1.2×1.8.2.2×3.12×1.3.4×1.3.7).

Effect at high subsonic speeds of fuselage forebody strakes on the static stability and vertical-tail-load characteristics of a complete model having a delta wing. E. C. Polhamus and K. P. Spreemann. N.A.S.A. T.N. D-903. May 1961.
Tests were made at Mach numbers from 0·60 to 0·92 corresponding to Reynolds numbers from $3{\cdot}0\times10^6$ to $4{\cdot}2\times10^6$, based on the wing mean aerodynamic chord, and at angles-of-attack from approximately −2° to 24°.—(1.8.1.2×1.8.2.2×1.6.1).

Analytical investigation of an adaptive flight-control system using a sinusoidal test signal. J. E. Harris. N.A.S.A. T.N. D-909. June 1961.—(1.8.0.1).

Static stability and control of canard configurations at Mach numbers from 0·70 to 2·22—triangular wing and canard with twin vertical tails. V. L. Peterson. N.A.S.A. T.N. D-1033. June 1961.
Static aerodynamic characteristics are presented for angles-of-attack from −6° to +18° at sideslip angles of 0° and 5°. Tests were made with the canard off and with the canard on at nominal deflection angles from 0° to 10°. The Reynolds number was 3·68 million based on the wing mean aerodynamic chord.—(1.8.1.2×1.8.2.2).

Large-scale wind-tunnel tests of an airplane model with an unswept, tilt wing of aspect ratio 5·5, and with four propellers and blowing flaps. J. A. Weiberg and C. A. Holzhauser. N.A.S.A. T.N. D-1034. June 1961.
The model was tested with flap deflections of 0° without BLC, 50° with and without BLC, and 80° with BLC for wing-tilt angles of 0°, 30°, and 50°. Included are results of tests of the model equipped with a leading-edge flap and the results of tests of the model in the presence of a ground plane.—(1.8.2.2×1.3.4).

Analysis of X-15 landing approach and flare characteristics determined from the first 30 flights. G. J. Matranga. N.A.S.A. T.N. D-1057. July 1961.
This paper presents lift, drag, and angle-of-attack data for various approach and landing configurations. The conditions and problems encountered during the approach pattern and the flare to touchdown are discussed. The value of flight simulations of the approach and flare manoeuvres is assessed.—(1.8.0.1×5.1×1.7.1×33.1.1).

THERMO-AERODYNAMICS *see also* BOUNDARY LAYER
COMPRESSIBLE FLOW

Experimental determination of the recovery factor and analytical solution of the conical flow field for a 20° included angle cone at Mach numbers of 4·6 and 6·0 and stagnation temperatures to 2600°R. F. A. Pfyl and L. L. Presley. N.A.S.A. T.N. D-353. June 1961.—(1.9.1×1.2.3.1).

Measurements of aerodynamic heat transfer on a 15° cone-cylinder-flare configuration in free flight at Mach numbers up to 4·7. C. B. Rumsey and D. B. Lee. N.A.S.A. T.N. D-824. May 1961.
Local Reynolds numbers based on body length to a measurement station varied from 2×10^6 to 138×10^6. Local Stanton numbers for each section of the body were obtained and are compared with theoretical values. Recovery factors, transition Reynolds numbers, and some heat-transfer data at angle-of-attack were also measured.—(1.9.1).

Simple formulas for stagnation-point convective heat loads in lunar return. F. C. Grant. N.A.S.A. T.N. D-890. July 1961.—(1.9.1×8.2).

Laminar heat-transfer and pressure-distribution studies on a

series of reentry nose shapes at a Mach number of 19·4 in helium. R. D. Wagner et al. *N.A.S.A. T.N. D-891. June* 1961.
The pressure and heat-transfer-rate distributions on the nose shapes are compared with theoretical predictions to ascertain the limitations and validity of the theories of hypersonic speeds. Two of the nose shapes were tested with variable-length-flow-separation spikes.—(1.9.1×1.1.1.4).

The effect of humidity on laminar recovery temperature measurements in supersonic flow of air in wind tunnels. J. F. W. Crane. R. & M. 3215. 1961.
Wind tunnel tests have been made at a Mach number of 2·92 to measure the effect of humidity on laminar recovery temperature on a cone. Consideration of the latent heat addition to the air in the condensation shock allows a theoretical estimate of recovery temperature to be made, based on true total temperature and true Mach number.—(1.9.1×1.12.1.3×1.5.1.4).

WINGS AND AEROFOILS *see also* BOUNDARY LAYER
LOADS
PERFORMANCE
TESTING AND INSTRUMENTS

Calculations of the lift slope and aerodynamic centre of cropped delta wings at supersonic speeds. J. H. B. Smith et al. *C.P.* 562. 1961.
The linearised theory of supersonic flow is used to calculate the lift slope and the aerodynamic centre of cropped delta wings which have subsonic leading edges. The cropped tip must be short enough for each tip to lie entirely upstream of the disturbances produced by the other. The results are presented graphically and in brief tables.—(1.10.2.2×1.8.2.2).

Unsteady motion of a wing of finite span in a compressible medium. E. A. Krasilshchikova. N.A.S.A. T.T. F-58. May 1961.—(1.10.1.2).

Ordinates and theoretical pressure-distribution data for NACA 6- and 6A-series airfoil sections with thicknesses from 2 to 21 and from 2 to 15 per cent chord, respectively. E. W. Patterson and A. L. Braslow. N.A.S.A. T.R. R-84. 1961.—(1.10.1.2×1.6.1).

An investigation at low speed of the flow near the apex of thin delta wings with sharp leading edges. B. J. Elle. R. & M. 3176. 1961.
The results of water tunnel experiments are presented. A systematic investigation of a series of flat-plate delta wings has been carried out in a water tunnel and the location of the centre-line of the rolled-up leading-edge vortex sheet has been determined as a function of apex and incidence. A description is also given of the effect of Reynolds number, leading-edge shape, secondary separation and half-model effects. The breakdown of the flow pattern at high incidence is demonstrated a few features of the breakdown mechanism are described.—(1.10.2.2×1.1.4.1).

An experimental investigation at supersonic speeds of the characteristics of two Gothic wings, one plane and one cambered. L. C. Squire. R. & M. 3211. 1961.
Tests have been made at supersonic speeds up to $M=2{\cdot}0$ on a thick cambered gothic wing of aspect ratio 0·75, together with tests on the uncambered wing of the same plan form and thickness. The camber was designed to give attached flow all along the leading edge, and over the whole wing, at one lift coefficient, together with low drag at this lift. The thickness distribution was chosen to have low zero lift drag and also to eliminate the adverse pressure gradients due to incidence and camber at the design lift.—(1.10.2.2).

TESTING AND INSTRUMENTS *see also* THERMO-AERODYNAMICS

The interference on a three-dimensional jet-flap wing in a closed wind tunnel. E. C. Maskell. R. & M. 3219. 1961.
The classical theory of wind tunnel interference is extended to cover interference on the effectiveness of a full-span jet flap issuing from the trailing edge of a high aspect ratio unswept wing. Corresponding corrections to tail height and setting are also given. Corrections to the observed downwash field over a limited interval downstream of the trailing edge of the wing are also derived.—(1.12.1×1.3.4).

Description and preliminary calibration of a low-density, hypervelocity wind tunnel. J. L. Potter et al. *A.E.D.C.-T.N.-61-83. August* 1961.—(1.12.1.3).

Effets de supports sur l'ecoulement a l'arriere d'un corps. P. Rebuffet. A.G.A.R.D. Report 302. *Mars.* 1959.—(1.12.1.3×1.10.1.4×1.10.3.4).

Exemples d'essais aerodynamiques pris hors de l'aeronautique classique. A. Martinot-Lagarde et A. Fauquet. A.G.A.R.D. Report 311. *Octobre* 1960.
The object of this report is to describe some tests in an aerodynamics laboratory but not forming part of standard aeronautical tests.—(1.12.1.1×2×5.3).

A design proposal for a water cooled 10″×10″ supersonic tunnel using the experiences gained from the development of a single-jack semiflexible nozzle. J. Rosen. K.T.H. Aero. T.N. 53. 1961.—(1.12.1.3).

Messeinrichtung fúr die Untersuchung der Druckverteilung im Strahl eines Mantelstromtriebwerkes. O. Lutz und K-D Emmenthal. D.F.L. Bericht 153. 1961. (*In German*).—(1.12.5×27.1×1.2.1.1).

AEROELASTICITY

See also TESTING AND INSTRUMENTS

A study of flutter at low mass ratios with possible application to hydrofoils. R. W. Herr. N.A.S.A. T.N. D-831. May 1961.
Experimental flutter-test results for some flexible cantilever-wing models partly submerged in water are presented. An explicit expression is presented which defines the lowest mass ratios for which representative section (flexure-torsion) flutter solutions are obtainable as a function of the various structural parameters.—(2×17.2).

Direct solution of the flutter problem. P. Lancaster. R. & M. 3206. 1961.
This note is a summary of some work on the problem of the solution of the flutter problem without resort to the usual "modal" approximations of semi-rigid theory. The method used is perfectly general and may be used to consider the flutter of a complete aircraft, although the examples given are restricted to cantilever lifting surfaces.—(2×33.2.3.0.0).

AIRCRAFT

See also AERODYNAMICS—STABILITY AND CONTROL
DESIGN AND CONSTRUCTION

Calculated normal load factors on light airplanes traversing the trailing vortices of heavy transport airplanes. W. A. McGowan. N.A.S.A. T.N. D-829. May 1961.
Results are presented of normal-load-factor calculations made for a light normal-category aeroplane and a light transport-category aeroplane traversing the wing-tip rolled-up trailing vortices of each of three heavy transport aeroplanes.—(3.6×5.3×33.1.1).

DESIGN AND CONSTRUCTION

See also EXTRA-ATMOSPHERIC TECHNOLOGY

Remarks on the status of Project Mercury. A. C. Bond and A. B. Kehlet. A.G.A.R.D. Report 290. *October* 1960.—(4.6×8.1×3.14).

AIRCRAFT OPERATION

See also AERODYNAMICS—STABILITY AND CONTROL
TESTING AND INSTRUMENTS
AIRCRAFT
INSTRUMENTS AND EQUIPMENT

Investigation of water-pond arresting of a dynamic model of a jet transport. W. C. Thompson. N.A.S.A. T.N. D-732. May 1961.—(5.3×5.5).

An investigation of landing-contact conditions for two large turbojet transports and a turboprop transport during routine daylight operations. J. W. Stickle. N.A.S.A. T.N. D-899. May 1961.
Presents statistical results of an investigation to determine the vertical velocity, air speed, rolling velocity, bank angle, and distance from the runway threshold, just prior to ground contact. A total of 395 landings of two turbojet transports and a turboprop transport were made on a dry runway at the Los Angeles International Airport.—(5.1×1.7.1×5.6×33.1.1).

EXTRA-ATMOSPHERIC TECHNOLOGY

See also AERODYNAMICS—STABILITY AND CONTROL
THERMO-AERODYNAMICS
DESIGN AND CONSTRUCTION

Variations of cosmic ray intensity. Yu. G. Shafer. N.A.S.A. T.T. F-67. August 1961.—(8.1×32.2.5).

Tables of Z functions for atmosphere entry analyses. D. R. Chapman and A. K. Kapphahn. N.A.S.A. T.R. R-106. 1961.—(8.2).

Results from a rocket-borne Langmuir probe experiment. G. P. Serbu. N.A.S.A. T.N. D-570. July 1961.
Data were obtained from a rocket-borne Langmuir probe experiment up to an altitude of 220 kilometers above Fort Churchill, Canada, in a quiet daytime ionosphere.—(8.1×32.2.5).

Analysis of error progression in terminal guidance for lunar landing. P. J. de Fries. N.A.S.A. T.N. D-605. July 1961.—(8.2×26×25.1).

Juno II Summary Project Report. Vol. 1. *Explorer VII Satellite. G. C. Marshall. Space Flight Center. N.A.S.A. T.N. D-605. July* 1961.—(8.2×8.1×11×32.2.5×4).

Horizon sensor performance in measuring altitude above the moon. P. J. de Fries. N.A.S.A. T.N. D-609. July 1961.
A space vehicle approaching the moon can determine its altitude above the surface by measuring the diameter of the apparent lunar disk with a horizon sensor and computing the distance with the knowledge of the lunar radius. Two basic errors are involved in this process: (1) an error introduced by measuring the chord of the lunar sphere, and (2) an error introduced by computing with an inaccurately known lunar radius. An error analysis is made considering these.—(8.2×11).

Radiation shielding for manned space flight. L. E. Wallner and H. R. Kaufman. N.A.S.A. T.N. D-681. July 1961.
Cosmic radiation, solar flares, the Earth's Van Allen belts, and nuclear radiation are assessed.—(8.1×32.2.5).

Power input to a small flat plate from a diffusely radiating sphere, with application to earth satellites. F. G. Cunningham. N.A.S.A. T.N. D-710. July 1961.
A general derivation is given for the radiation incident on a small flat plate from a uniformly radiating sphere.—(8.2×8.1×32.2).

A sequence diagram analysis of the Vanguard satellite launching vehicle. W. J. D. Escher and R. W. Foster. N.A.S.A. T.N. D-782. May 1961.—(8.2×11).

Study of the use of a terminal controller technique for reentry guidance of a capsule-type vehicle. E. C. Foudriat. N.A.S.A. T.N. D-828. May 1961.
A study has been made of the use of a terminal controller technique in the guidance of a capsule-type re-entry vehicle to a desired landing point.—(8.2×25.1).

Analytical evaluation of a method of midcourse guidance for rendezvous with earth satellites. J. M. Eggleston and R. S. Dunning. N.A.S.A. T.N. D-883. June 1961.
A digital-computer simulation was made of the mid-course (or ascent) phase of a rendezvous between a ferry vehicle and a space station.—(8.2).

Study of a solar sensor for use in space-vehicle orientation control systems. P. R. Spencer. N.A.S.A. T.N. D-885. June 1961.
Consideration has been given to such requirements as reliability, capture capability, sensitivity, and power consumption. The effects of varying certain design parameters are shown and improvements are suggested. The effects of a space environment are discussed. Results obtained from an experimental model of a solar sensor are presented.—(8.2×26).

Study of an active control system for a spinning body. J. J. Adams. N.A.S.A. T.N. D-905. June 1961.—(8.2×25.1).

A fixed-base-simulator study of the ability of a pilot to establish close orbits around the moon. M. J. Queijo and D. R. Riley. N.A.S.A. T.N. D-917. June 1961.—(8.2×25.1).

Two instruments for measuring distributions of low-energy charged particles in space. M. Bader et al. *N.A.S.A. T.N. D-1035. July* 1961.

Some methods and instrumentation for measuring the energy and density distribution of low-energy (0 to 20 kev) ions in space are considered from the standpoint of suitability for space vehicle payloads.—(8.2×18.1×32.2.5).

Velocity requirements for abort from the boost trajectory of a manned lunar mission. R. E. Slye. N.A.S.A. T.N. D-1038. July 1961.
An investigation is made of the abort velocity requirements associated with failure of a propulsion system for a manned lunar mission.—(8.2).

Density in a planetary exosphere. J. Herring and H. L. Kyle. N.A.S.A. T.N. D-1042. July 1961.
A discussion of the Opik-Singer theory of the density of a planetary exosphere is presented. Their density formula permits the calculation of the depth of the exosphere. Since the correctness of their derivation of the basic formula for density distribution has been questioned, an alternate method directly on Liouville's theorem is given. It is concluded that the Opik-Singer formula seems valid for the ballistic component of the exosphere; but for a complete description of the planetary exosphere, the ionised and bound-orbit components must also be included.—(8.1×32.2.5×24).

Sporadic-E as observed with rockets. J. C. Seddon. N.A.S.A. T.N. D-1043. July 1961.—(8.1×32.2.5).

Measurements of sheath currents and equilibrium potential on the Explorer VIII satellite (1960). *R. E. Bordeau* et al. *N.A.S.A. T.N. D-1064. July* 1961.
Experimental data were obtained from the Explorer VIII satellite on five parameters pertinent to the problem of the interaction of space vehicles with an ionised atmosphere.—(8.2×32.2.5×11).

On the electron density distribution above the F-2 peak. S. J. Bauer. N.A.S.A. T.N. D-1065. July 1961.—(8.1×32.2.5).

The effect of lateral- and longitudinal-range control on allowable entry conditions for a point return from space. A. G. Boissevain. N.A.S.A. T.N. D-1067. July 1961.
The problem of return to a specified landing point on the earth from space is considered by studying the interaction between an assumed representative control over the lateral and longitudinal range and the initial conditions of approach to the earth.—(8.2).

Sampling dust from the stratosphere. P. W. Hodge. Smithn. Cont. to Astro. Vol. 5. No. 10. 1961.—(8.1×24).

AVIATION MEDICINE

See AERODYNAMICS—STABILITY AND CONTROL

ELECTRONICS

See EXTRA-ATMOSPHERIC TECHNOLOGY
INSTRUMENTS AND EQUIPMENT
MATERIALS

FLIGHT TESTING

See also STABILITY AND CONTROL
AERODYNAMICS

Test and evaluation of U.S. Navy Aircraft Weapons Systems. J. B. Paradis. A.G.A.R.D. Report 285. *October* 1960.
This paper is divided into five parts: (1) The birth of a Naval aircraft weapon system; (2) The concept of Navy testing; (3) The Navy's testing organisation; (4) A chronology of the tests; (5) Management of the tests. Detail test procedures are not discussed, but these conform to normal practice.—(13).

HYDRODYNAMICS

See AEROELASTICITY

INSTRUMENTS AND EQUIPMENT

See also EXTRA-ATMOSPHERIC TECHNOLOGY

Polyester film belts. J. H. Licht and A. White. N.A.S.A. T.N. D-668. May 1961.
This paper indicates performance based on a limited number of tests; suggests design criteria and describes fabrication procedure, applications, and superior characteristics.—(18.1×21.3.3).

A digital recording system for satellite tracking data. T. P. Sifferlen and W. M. Hocking. N.A.S.A. T.N. D-672. May 1961.
A digital recording system has been designed and built for recording satellite tracking data, on five-level punched paper tape at a rate of 100 characters per second. The punch code is identical with that used in teletypewriter communication.—(18.1×11×26).

A resume of simulation techniques and icing activities at the Engine Laboratory of the National Research Council (Canada). M. S. Chappell. N.R.C. Report L.R.-305. May 1961.
This paper presents a brief description of the facilities available for aircraft engine icing studies at the Engine Laboratory of the National Research Council (Canada), together with a more detailed discussion of simulation and measurement techniques. Test results from the past few seasons are presented in the form of observed phenomena associated with general engine and anti-icing system types.—(18.5×27.1×24×5.3).

MATERIALS

See INSTRUMENTS AND EQUIPMENT

The sintered copper powder. Ye. M. Savitskiy and A. I. Vlasov. N.A.S.A. T.T. F-64. June 1961.
The authors studied the structure, resistivity, oxidation resistance, mechanical properties, and manufacturing processes of sintered copper powder when alumina, silica, or magnesia is added.—(21.2.2).

Sputtering of metals by mass-analyzed N_2^+ and N^+ M. Bader et al. *N.A.S.A. T.R. R-105.* 1961.—(21.2×11×32.2).

Investigation of three analytical hypotheses for determining material creep behavior under varied loads, with an application to 2024-T3 aluminium-alloy sheet in tension at 400°F. A. Berkovits. N.A.S.A. T.N. D-799. May 1961.
Time-hardening, strain-hardening, and life-fraction hypotheses are formulated mathematically to estimate tensile creep strain under varied loads and constant temperature from creep data obtained under constant load and constant temperature.—(21.2.2).

Tensile properties of 17-7PH and 12MoV stainless-steel sheet under rapid-heating and constant-temperature conditions. C. R. Manning and H. L. Price. N.A.S.A. T.N. D-823. May 1961.—(21.2.1).

Investigation of oxidation-resistant coatings on graphite and molybdenum in two arc-powered facilities. R. W. Peters and T. A. Rasnick. N.A.S.A. T.N. D-838. July 1961.
A number of leading-edge specimens were tested in a 6-inch subsonic low-pressure arc-powered tunnel and a 1,500-kw subsonic arc jet to determine the effectiveness of a siliconised coating for ATJ graphite and W-2 and Durak MG coatings for 0·5-per cent-titanium—molybdenum alloy in preventing the oxdiation of these materials.—(21.3).

Stability of refractory compounds in hydrogen between 4500° and 5000°F, and their compatibility with tungsten. C. E. May and P. D. Hoekstra. N.A.S.A. T.N. D-844. May 1961.—(21.3×32.1).

Investigations of the deterioration of 22 refractory materials in a Mach number 2 jet at a stagnation temperature of 3,800°F. B. W. Lewis. N.A.S.A. T.N. D-906. June 1961.
The data include change in weight curves, approximate surface temperature of model near stagnation point, and observations as to visually apparent physical changes in the surface of the models.—(21).

A study of external insulation requirements for the extension of aluminium alloy structures to hot supersonic aircraft. W. Wiebe. N.R.C. Report L.R.-306. May 1961.
An analysis, based on the ability of an externally insulated aluminium alloy structure to equal the performance of a similar uninsulated titanium structure on the basis of panel stability, has been made to establish the required characteristics of the external insulation material for Mach 3·5 flight conditions. Appended is a survey of refractory material properties, and the mechanism of heat transfer through porous insulation materials is briefly reviewed.—(21.2.2×34.3).

Comparative investigation on some structural adhesives for elevated temperature. A. Hartman. N.L.L.-T.N. M. 2083. October 1960.
Three high-temperature adhesives are compared for tensile shear strength and flatwise tensile strength at temperatures up to 250°C and sandwich peel strength at room temperature.—(21.7×33.2.4.13.9).

Contribution a l'étude des phénomènes aux électrodes au cours de la dissolution anodique du cuivre dans l'acide phosphorique concentré. M-C Petit. Pubs. Sc. et Techs. N.T. 97. 1961. (*In French*).—(21.2.2×32.1).

MATHEMATICS

Tables of rocket functions for non-zero damping. J. Guest. A.R.L. Note G.W. 14. June 1960.
The rocket functions with non-zero damping occur in the study of the dynamic behaviour of a rocket during boost and have so far received little attention for accurate tabulation: such tabulation is the subject of this paper.—(22.2×25.2).

A direct method for estimating the effect of coulomb friction on free oscillations. M. D. Frost. A.R.L. Note A 182. May 1960.—(22.2×18).

Actes des colloques de calcul numérique. M. Arend et al. *Pubs Sc. et Techs. N.T. 98.* 1961. (*In French*).—(22).

Actes du colloque "calcul numerique, calcul physique." M. Kivéliovitch et al. *Pubs. Sc. et Techs. N.T. 99.* 1961. (*In French*).—(22).

METEOROLOGY

See EXTRA-ATMOSPHERIC TECHNOLOGY
INSTRUMENTS AND EQUIPMENT

Empirical three-sigma wind component profiles of 45-degree missile flight azimuth. Atlantic missile range Patrick A.F.B. (Cape Canaveral), Florida. W. W. Vaughan. N.A.S.A. T.N. D-606. July 1961.—(24×26).

Range of density variability from surface to 120 km altitude. O. E. Smith and H. B. Chenoweth. N.A.S.A. T.N. D-612. July 1961.—(24).

The relationship between the discrete gust and power spectra presentations of atmospheric turbulence, with a suggested model of low-altitude turbulence. J. K. Zbrozek. R. & M. 3216. 1961.
The relation between the discrete gust and spectral presentations of atmospheric turbulence is discussed and the limitations of the discrete gust approach pointed out. The available measurements of low-altitude turbulence are analysed. The relationships between the three components of turbulence at low altitude and the effect of wind are considered. A model of atmospheric turbulence in a temperate climate at 250 ft. above the terrain is suggested.—(24×33.1.1).

MISSILES

See AERODYNAMICS—LOADS
STABILITY AND CONTROL
EXTRA-ATMOSPHERIC TECHNOLOGY
MATHEMATICS

NAVIGATION

See EXTRA-ATMOSPHERIC TECHNOLOGY
INSTRUMENTS AND EQUIPMENT
METEOROLOGY

POWER PLANTS

See AERODYNAMICS—INTERNAL FLOW
PERFORMANCE
STABILITY AND CONTROL
TESTING AND INSTRUMENTS
INSTRUMENTS AND EQUIPMENT

SCIENCE GENERAL

See AERODYNAMICS—FLUID DYNAMICS
EXTRA-ATMOSPHERIC TECHNOLOGY

STRUCTURES

See AERODYNAMICS—LOADS
STABILITY AND CONTROL
AIRCRAFT
AIRCRAFT OPERATION

Nature looks after her own; Dunlop sees to the needs of man's invention

The wide range of Dunlop aircraft accessory equipment is matched by the Company's far-reaching Service Organization, providing operators with comprehensive servicing facilities for the many Dunlop components fitted to aircraft flying in all parts of the world.

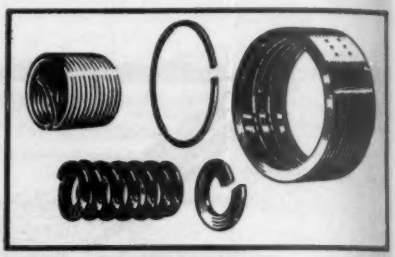
"Dunlop tyres, wheels, and brakes" is a phrase made familiar by repetition in the aircraft industry over many years—and today the range of the Company's equipment extends from complete wheel assemblies to control equipment for weapon systems; from windscreen wipers to thrust reversal controls; from electrical components to de-icing equipment, and includes components and installations for projects still under development.

DUNLOP

Dunlop Rubber Company Ltd. (Aviation Division) · Foleshill · Coventry · (Coventry 68733)

cm/av/13

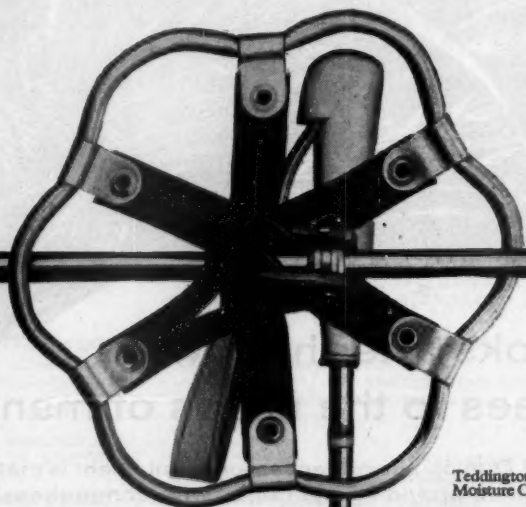
Outstanding for precision and reliability, Cross wire thread inserts, coils, rings and spring washers have won world wide renown. Manufactured in high carbon steel, stainless steel and bronze to suit any specific application.



CROSS Mfg. Co. (1938) Ltd.
Combe Down, Bath.
Tel: Combe Down 2355/8.

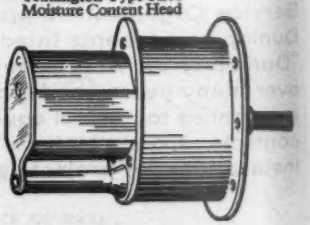
looked at

from
any angle



. . . ski-ing is an exhilarating sport. But look at ice from some angles and you have a problem—such as aircraft icing-up. This is one of the many problems that Teddington have taken care of. Their range of anticing control equipment — like all the other precision control equipment they make—is used throughout the British aircraft industry.

Teddington Type PBA
Moisture Content Head



Teddington
CONTROLS

REGD TRADE MARK

TEDDINGTON AIRCRAFT CONTROLS LIMITED
MERTHYR TYDFIL · SOUTH WALES · TELEPHONE: MERTHYR TYDFIL 3261
London Office: Colnbrook By-Pass, West Drayton, Middx.
Telephone: Colnbrook 2202

TAC814

16 OUT OF 18 AIRLINES USING GATWICK HAVE THEIR AIRCRAFT FUELLED BY SHELL AND BP AVIATION SERVICES

SHELL-MEX AND B.P. LTD

Shell-Mex House London WC2 · Registered Users of Trade Marks

DISTRIBUTORS IN THE UNITED KINGDOM FOR THE SHELL AND BP GROUPS

NEW FROM PERGAMON

TRANSONIC WIND TUNNEL TESTING

BERNHARD H. GOETHERT, Arnold Engineering Development Center, U.S.A.
This AGARDograph presents a review of the extensive efforts made during the last 15 years to develop practical transonic wind tunnels and discusses their performance and limitations. Emphasis is placed on the design and operational characteristics of both types of modern transonic wind tunnels, that is, on wind tunnels with either longitudinally slotted or perforated test sections. Each chapter of this volume has been made as complete as possible, with its own series of figures and a separate list of references and bibliographical material.

£5 5s. net ($17.50)

PULSATING COMBUSTION

The Collected Works of F. H. REYNST
Edited by M. W. THRING, Professor of Fuel Technology and Chemical Engineering, University of Sheffield.
The fields of application dealt with in this book are mainly boilers and gas turbines (the latter in particular for aircraft propulsion). In the introduction, written by Professor M. W. Thring, Reynst's novel contributions to combustion science are enumerated and references to the papers describing the ideas are given. Professor Thring distinguishes eight important new contributions to combustion technology arising from Reynst's work which are developed more or less explicitly in the different papers.

£5 net ($15.00)

FULL SCALE FATIGUE TESTING OF AIRCRAFT STRUCTURES

Edited by F. J. PLANTEMA and J. SCHIJVE, National Aeronautical Research Institute, Amsterdam.
Authoritative proceedings of a recent Symposium dealing with the planning and interpretation of full-scale aircraft fatigue tests, comprising such topics as fatigue testing full-scale structures for studying crack propagation and load redistribution; "fail-safe" strength determination; and fatigue test programmes and results for specific aircraft. Other important subjects discussed are test equipment and procedures, and fatigue strength requirements for aircraft.

£5 net ($15.00)

PROGRESS IN AERONAUTICAL SCIENCES

Volume 2
Edited by A. FERRI, D. KUCHEMANN and L. H. G. STERNE
Includes the following valuable papers—Turbulent Boundary Layers in Incompressible Flow—J. C. Rotta; Boundary Layers in Three Dimensions—J. C. Cooke and M. G. Hall; Some Aerodynamic Principles for the Design of Swept Wings—J. A. Bagley; Ducted Propellers—A Critical Review of the State of the Art—A. H. Sacks and J. A. Burnell; Experimental Facilities for Hypersonic Research—R. N. Cox; Meteorological and Aeronautical Aspects of Atmospheric Turbulence—Hans A. Panofsky and Harry Press.

Approx. £5 5s. ($15.00)

THE THEORY OF TRANSONIC FLOW

K. G. GUDERLEY
This extremely well organised book is a systematic representation of the theory of transonic flow. It is written for the engineer who has a good background in mathematics or who has strong mathematical leanings, and for the applied mathematician who wants to understand the specific problems of transonic flow. Particular emphasis has been given to a development of the ideas that lead to a mathematical formulation, i.e. in this monograph the author tries to show something of the mixture of intuition and rigor which is characteristic of research.

63s. net ($15.00)

TOPICS IN ENGINEERING LOGIC

MORTON NADLER
Presents a great deal of work previously unpublished on methods for the design of synchronous, aperiodic circuits capable of direct application at both the hardware and logical design levels. Powerful minimization and simplification techniques are also presented. Of great value is the authors' own research on the treatment of operational circuits and the theory of critical functions.

Approx. 40s. ($6.00)

ADVANCES IN AERONAUTICAL SCIENCES

Volumes 3 and 4
Editorial Committee:
Chairman: Th. von KARMAN
A. M. BALLANTYNE, R. R. DEXTER, G. BOCK, M. ROY and H. L. DRYDEN
These two volumes contain the authoritative proceedings of the Second International Congress in the Aeronautical Sciences held at Zurich.

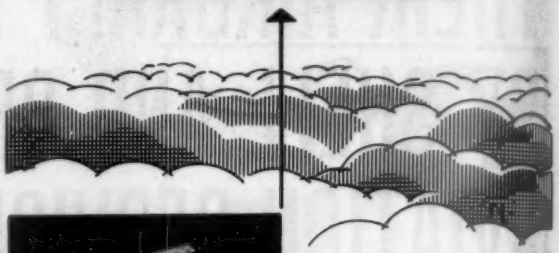
Per set of two volumes £15 net ($45.00)

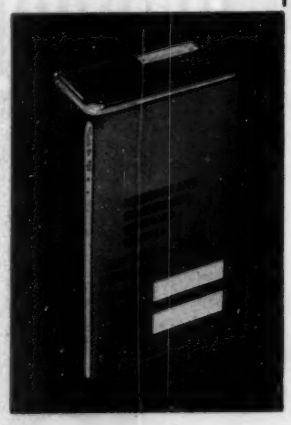
Pergamon Press

OXFORD LONDON NEW YORK

Headington Hill Hall, Oxford
4 & 5 Fitzroy Square, London, W.1
122 East 55th Street, New York 22, N.Y.

PRECISION EQUIPMENT FOR TOP FLIGHT ACCURACY





triple bridge units

PLUG-IN UNITS FOR ERROR CORRECTION AND F.S.D. CHANGES

Disregard resistance of leads. Give voltage as function of temperature. Simplify switching. Correct sensor calibration errors. Fit reading or recording instruments.

Complete range for:
RESISTANCE THERMOMETERS
PRECISION MEASUREMENTS
MULTI-POINT SENSING SYSTEMS

platinum resistance thermometers

IMPROVED DESIGN GIVING HIGH ACCURACY AND RELIABILITY

High and low temperatures. Special miniature designs. Fast response.

Complete range for:
AERODYNAMIC APPLICATIONS
INDUSTRIAL PROCESSES
RESEARCH AND INVESTIGATIONS

RESEARCH & ENGINEERING CONTROLS LTD

SOUTH BERSTED INDUSTRIAL ESTATE · BOGNOR REGIS · SUSSEX
Telephone: Bognor Regis 4101/2/3 Telegrams: Sensor, Bognor Regis
T13/RE

BRITISH AIRCRAFT CORPORATION

and

Honeywell

have formed

"INERTIAL GUIDANCE -EUROPE"

Through one central marketing organisation Inertial Guidance-Europe offers the design, development and production resources of British Aircraft Corporation and Honeywell in the fields of inertial guidance systems and miniature inertial components.

IW.7

Lifting Power of Air Propellers

In the design of suitable lifting propellers for aeronautical purposes, there are many practical and theoretical points to be considered. Taking into consideration the weight of the propeller, there is a particular thrust per h.p. which will give the highest efficiency . . . . It is clear that the thrust and h.p. can be approximately arrived at for any particular speed. For instance, to drive propeller E at 100 revolutions per minute it would require about 100 b.h.p. and give a thrust of 1,125 pounds.
. . . . propeller E, at 45 revolutions per minute, gave a thrust of 240 lbs. with 14 I.H.P., or at 17·1 lbs. per I.H.P. Now this figure can be considerably improved:

(1) By reducing the skin friction of the surface.
(2) By reducing the resistance of the blade structure.

TABLE V.

PROPELLER E. DATE OF EXPERIMENT: OCTOBER 20TH, 1899.

4 WIDE BLADES. AREA, 350 SQUARE FEET. ANGLE OF BLADES, 21 DEGREES.

Revolutions of Propeller per minute	20	25	30	35	40	45	50	55	60
Tip Speed in feet per minute	1,880	2,350	2,820	3,290	3,760	4,230	4,700	5,170	5,640
Thrust in Pounds	55	77	104	136	179	240	280	340	405
I.H.P.	1·1	2·6	4·2	6·3	9·6	14·0	18·7	23·3	32·0
B.H.P.	·4	1·5	2·7	4·3	6·7	9·8	13·5	16·3	23·0
Thrust per B.H.P.	150	52	38·7	31·7	26·6	24·4	21·4	20·9	18·0
Thrust per I.H.P.	52·4	29·6	24·9	21·6	18·6	17·1	15·0	14·6	12·6
H.P. Friction of Unloaded Engine	·7	·9	1·1	1·3	1·5	1·8	2·1	2·3	2·6

TABLE VIII.

PROPELLER E. DATE OF EXPERIMENT: OCTOBER 20TH, 1899.

AIR READINGS.

4 WIDE BLADES. AREA, 350 SQUARE FEET. ANGLE OF BLADES, 21 DEGREES. AIR DISCHARGED PER MINUTE, 363,144 CUBIC FEET. REVOLUTIONS PER MINUTE, 32½. THRUST, 120 POUNDS. INDICATED HORSE POWER, 5·8.

Radius in feet	2	4	6	8	10	12	14	16
Velocity of Air per minute...	155	209	363	561	657	724	426	3½

From "Lifting Power of Air Propellers, being Experiments with Propellers 30 ft. in Diameter," by William George Walker, A.M.I.C.E., M.I.M.E., "The Aëronautical Journal," Volume IV, No. 16, October 1900.

The 23 Annual Reports of the Aëronautical Society, covering the years 1866-1893, and the early volumes of "The Aëronautical Journal" which succeeded the Reports, are contemporary records which must ever remain an important source of aeronautical information which is not given to the same extent elsewhere.

These rare volumes, for many years virtually unobtainable, are now, with the full co-operation of the Royal Aeronautical Society, again available in a facsimile reprint which itself is likely to become rare as interest in aeronautical history grows.

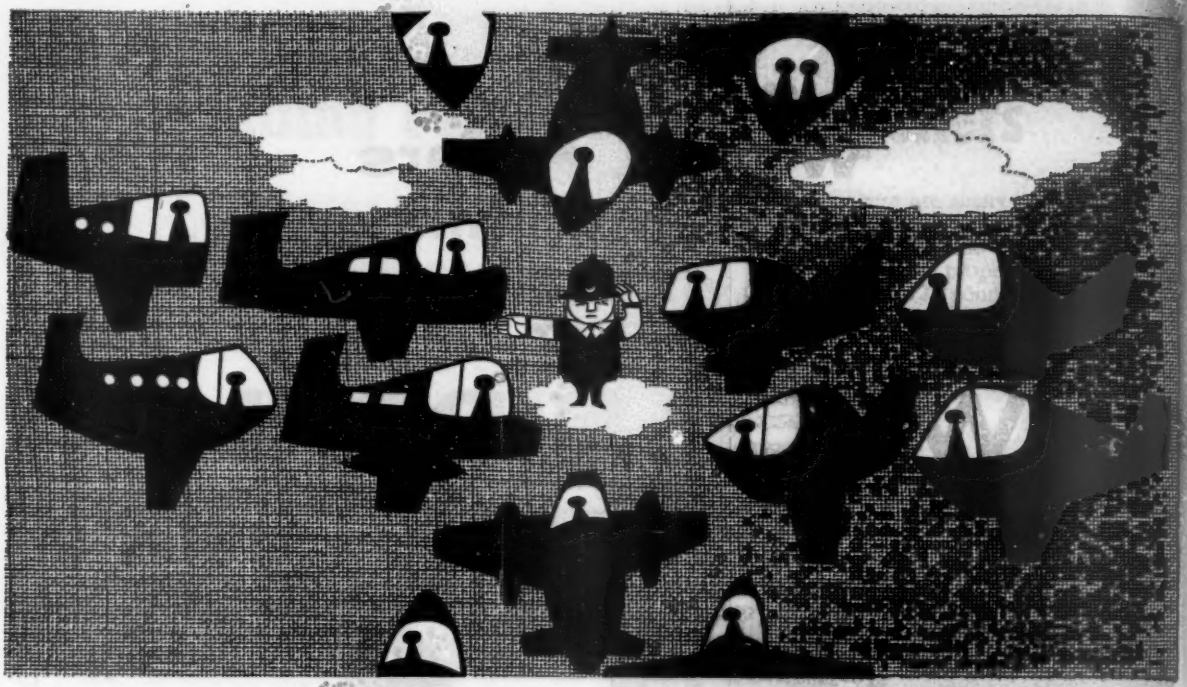
The 23 Annual Reports 1866-1893 in four volumes, **£50.**
The first 15 volumes of "The Aëronautical Journal" 1897-1911 in five volumes, **£67 10s. 0d.**

PETER MURRAY HILL (PUBLISHERS) LTD.
73 SLOANE AVENUE, CHELSEA, LONDON, S.W.3
Telephone : KNightsbridge 4381/2

World Leaders in Civil and Military Aviation...

HAWKER SIDDELEY AVIATION

AVRO · AWA · BLACKBURN · DE HAVILLAND · FOLLAND · GLOSTER · HAWKER



IN TOUCH WITH AIR TRAFFIC

The Cossor CRD 23 is an advanced display system for the PPI presentation of air traffic control information.

Refinements can be added to the simple basic equipment at any time to suit particular installations and changing requirements. The small range of supplementary units are in standard sizes and can be variously combined to cover a wide range of needs.

The equipment is designed for simplicity of installation and for economy of such items as repeaters, amplifiers and cables.

CRD 23 RADAR DISPLAY SYSTEM

For full information about the many advantages of the CRD 23 system please write to:—

COSSOR
RADAR & ELECTRONICS LTD

COSSOR THE PINNACLES, ELIZABETH WAY, HARLOW, ESSEX ENGLAND TEL: HARLOW 26862

APPOINTMENTS

Semi-displayed advertisements for inclusion in this section are charged at £4 4s. 0d. per single column inch. Small advertisements less than 1" without display are charged at 12/6d. per line. Ordinary displayed advertisements are charged at full display rates. Box numbers—1/- extra. Replies should be addressed to: Box 000, care of THE JOURNAL of the Royal Aeronautical Society, Oxford House, 15 Cranswall, London E.C.3.
Remittances—Cheques and postal orders should be made payable to THE JOURNAL of the Royal Aeronautical Society, Oxford House, 15 Cranswall, London E.C.3.
The Society reserves the right to decline any copy or advertisement at its discretion and accepts no responsibility for delay in publication or for clerical or printer's errors, although every care is taken to avoid mistakes.
Orders and copy should be sent to the Advertisement Offices, THE JOURNAL of the Royal Aeronautical Society, Oxford House, 15 Cranswall, London E.C.3 by the 10th of the preceding month.

1961-62 edition published
13th December £5.5.0

Jane's *all the world's* **Aircraft**

Edited by JOHN W. R. TAYLOR, A.R.AE.S., F.R.HIST.S.

Drones
Missiles
Airships
Aeroplanes
Helicopters
Aero-engines
Space Vehicles
VTOL/STOL Aircraft
Research Prototypes
Ground Effect Vehicles

SAMPSON LOW, 16 MADDOX ST, LONDON W.1.

NORTHAMPTON COLLEGE OF ADVANCED TECHNOLOGY

DEPARTMENT OF AERONAUTICS AND SPACE TECHNOLOGY

ROCKET DYNAMICS

The Department of Aeronautics and Space Technology invites applications for enrolment to the Course of 22 lectures in Rocket Dynamics on Mondays from 6.45 - 9.00 p.m., commencing on 8th January 1962. This is a fundamental course suitable for final year students, graduates, engineers, scientists, and lecturers in aerodynamics, mechanical engineering, applied mathematics and physics. The lecturer will be G. A. Tokaty, D.Eng., D.Ae.Sc., Ph.D., A.F.I.A.S., A.F.R.Ae.S., Head of Department.

Fee £5. Syllabus and enrolment cards can be obtained from the Secretary of the College, St. John's Street, London, E.C.1.

THE COLLEGE OF AERONAUTICS

TWO-YEAR DIPLOMA COURSE 1962-1964

Applications are invited from suitably qualified men and women who wish to enrol for the Two-Year Diploma Course which begins in October 1962.

This post-graduate course in Aeronautical Science and Engineering is intended primarily for University Graduates in Engineering, Science or Mathematics. Technical College students and others who possess a Higher National Certificate, Diploma or equivalent qualification and attain the required entrance examination standard may also be accepted. The Curriculum includes the subjects of Aerodynamics, Aircraft Design, Electrical and Control Engineering, Materials, Production and Industrial Administration and Aircraft Propulsion in all of which subjects a major specialisation may be taken. Lectures and laboratories in Mathematics and Flight are obligatory for all students.

All applications will be considered by the Board of Entry which may call candidates to attend at the College for written Entrance Examination in Engineering, Physics, Mechanics and Mathematics, to be held on Monday 2nd April 1962. Exemption from this examination will normally only be given to candidates possessing approved university degrees in Science or Engineering, or reading for such degrees. The Board may also require attendance for personal interview at a later date.

Candidates who possess Bachelors Degrees with 1st or 2nd Class Honours in Aeronautics, and also in Science or Engineering if they have adequate post-graduate experience may, at the discretion of the Board of Entry, be accepted for entry to the second year of the course and qualify for the Diploma (D.C.Ae.).

Further information about the course and forms of application, which must be completed and returned not later than Saturday 10th March 1962, may be obtained from the Registrar, The College of Aeronautics, Cranfield, Bletchley, Bucks.

TRADE MARKS SECTION

AIRCRAFT MATERIALS LTD.

STRUCTURAL MATERIALS
and COMPONENTS

ASSOCIATED ELECTRICAL INDUSTRIES LTD.

AEI

ELECTRICAL EQUIPMENT
for Aircraft
Associated Electrical Industries Ltd
Aircraft Equipment Group

TRADE MARKS—*Continued*

THE AVIATION SERVICE OF BRITISH PETROLEUM

AIR BP

LIGHT-METAL FORGINGS LTD.

LMF

THE BRITISH REFRASIL DIVISION OF DARCHEM ENGINEERING LTD.

REFRASIL

LIGHTWEIGHT, HIGH TEMPERATURE INSULATION

LOCKHEED PRECISION PRODUCTS LTD.

ALL BRITISH Lockheed REGD. TRADE MARK

hydraulics

ELECTRO-HYDRAULICS LTD.

EH LIMITED

LIVERPOOL ROAD, WARRINGTON

LUCAS GAS TURBINE EQUIPMENT LTD.

LUCAS

KELVIN & HUGHES (AVIATION) LTD.

KH

ROBERT RILEY LIMITED

RR FAMOUS FOR SPRINGS SINCE 1681

Precision Springs

K.L.G SPARKING PLUGS LTD.

K·L·G

SPARKING PLUGS AND IGNITION EQUIPMENT

ROTAX LTD.

ROTAX

AIRCRAFT ELECTRICAL ENGINEERS

SMITHS AVIATION DIVISION

SMITHS

SPERRY GYROSCOPE CO. LTD.

SPERRY

SPERRY GYROSCOPE COMPANY LIMITED
Telephone ISLeworth 1241

JOURNAL BINDING

Permanent Binding :

Previous Volumes (including packing and postage in the United Kingdom) ... ... £1 7s. 0d.

1960 Volume (including packing and postage in the United Kingdom) ... ... £1 5s. 0d.

Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Members are asked to be certain that the address to which they want their Journals sent is the same on their letters to The Lewes Press and to the Society.

DIRECTORY OF ADVERTISERS

AIRCRAFT ENGINEERING
12 Bloomsbury Square, London, W.C.1. *Holborn* 4842

AIRCRAFT MATERIALS LTD.
Midland Road, London N.W.1. *Euston* 6151

ASSOCIATED ELECTRICAL INDUSTRIES LTD.
Lower Ford Street, Coventry. *Coventry* 64181

AUTONETICS (NORTH AMERICAN AVIATION, INC.)
Downey, California, U.S.A.
European Office: 29 Rue Coulouvreniere.
Geneva, Switzerland.

BLACKBURN AIRCRAFT LTD.
Brough, Yorks. *Brough* 67121
43 Berkeley Square, W.1. *Grosvenor* 5771-8

BLACKHEATH STAMPINGS CO. LTD.
Blackheath, Birmingham *Blackheath* 1448-9

B.P. AVIATION SERVICE, SHELL-MEX AND B.P. LTD.
Shell-Mex House, Strand, London W.C.2. *Temple Bar* 1234

BRISTOL SIDDELEY ENGINES LTD.
London Office: Mercury House,
195 Knightsbridge, S.W.1. *Kensington* 7090
Bristol: P.O. Box 3, Filton, Bristol, England. *Bristol* 693871
Coventry: P.O. Box 17, Coventry, Warwickshire,
England. *Coventry* 27666

BRITISH AIRCRAFT CORPORATION
100 Pall Mall, London, S.W.1. *Whitehall* 1020

BRITISH EXECUTIVE AND GENERAL AVIATION LTD. (BEAGLE)
Sceptre House, 169 Regent St., London W.1. *Regent* 3101-5

BRITISH OVERSEAS AIRWAYS CORPORATION
Head Office: London Airport, Hounslow, Middx. *Skyport* 5511
Passenger Reservations and Enquiries:
Airways Terminal, Buckingham Palace Road,
London, S.W.1 *Victoria* 2323

THE BRITISH REFRASIL DIV. OF DARCHEM ENGINEERING LTD.
Stillington, Co. Durham. *Stillington* 351

BRITISH TIMKEN DIVISION OF THE TIMKEN ROLLER BEARING CO. LTD.
Duston, Northampton. *Northampton* 4921

CROSS MANUFACTURING CO. (1938) LTD.
Bath, Somerset. *Combe Down* 2355/8

DE HAVILLAND AIRCRAFT CO. LTD.
Hatfield, Herts. *Hatfield* 2345

DE HAVILLAND ENGINE CO. LTD.
Leavesden, Nr. Watford, Herts. *Garston* 4000

DOWTY GROUP LTD.
Cheltenham, Glos. *Cheltenham* 53471

DOWTY ROTOL LTD.
Cheltenham Road, Gloucester *Gloucester* 24431

DUNLOP RUBBER CO. LTD.
Aviation Division, Foleshill, Coventry. *Coventry* 88733

ELECTRO-HYDRAULICS LTD.
Liverpool Road, Warrington. *Warrington* 35241

ENGLISH ELECTRIC CO. LTD.
Marconi House, Strand, London W.C.2. *Covent Garden* 1234

E.N.V. ENGINEERING CO. LTD.
Hythe Road, Willesden, London N.W.10. *Ladbroke* 3622

FIRTH-VICKERS STAINLESS STEELS LTD.
Staybrite Works, Sheffield. *Sheffield* 42031

FOX, SAMUEL & CO. LTD. (UNITED STEEL COMPANIES LTD.)
17 Westbourne Road, Sheffield 10. *Sheffield* 40871

GENERAL ELECTRIC CO. LTD.
Magnet House, Kingsway, London W.C.2. *Temple Bar* 8000

HAWKER SIDDELEY AVIATION LTD.
Richmond Road, Kingston-on-Thames. *Kingston* 7741
32 Duke Street, St. James's, London S.W.1. *Whitehall* 2064

HOBSON, H. M. LTD.
Hobson Works, Fordhouses, Wolverhampton *Fordhouses* 2266

HUNTING AIRCRAFT LTD.
Luton Airport, Luton, Bedfordshire. *Luton* 6060

IMPERIAL CHEMICAL INDUSTRIES LTD.
Plastics Division, Black Fan Road,
Welwyn Garden City, Herts. *Welwyn Garden* 3400

IMPERIAL CHEMICAL INDUSTRIES LTD. (TITANIUM)
London S.W.1. *Victoria* 4444

INERTIAL GUIDANCE
100 Pall Mall, London, S.W.1. *Whitehall* 1020

KELVIN & HUGHES (AVIATION) LTD.
New North Road, Barkingside, Essex *Hainault* 2601

K.L.G. SPARKING PLUGS LTD.
Putney Vale, London S.W.15. *Putney* 6111

LIGHT-METAL FORGINGS LTD.
Oldbury, Birmingham. *Broadwell* 1122

LOCKHEED PRECISION PRODUCTS LTD.
Shaw Road, Speke, Liverpool 24, Lancs.

LUCAS GAS TURBINE EQUIPMENT LTD.
Shaftmoor Lane, Birmingham, 28 *Springfield* 2311
Burnley. *Burnley* 5851 & 5217

MAGNESIUM ELEKTRON LTD.
Lumms Lane, Clifton Junction, nr. Manchester. *Swinton* 2511-9
5 Charles II Street, London W.1. *Trafalgar* 1066

NAPIER, D. & SON LTD.
The Vale, Acton, London W.3. *Shepherds Bush* 1200

NORMALAIR LTD.
West Hendford ,Yeovil, Somerset. *Yeovil* 1100

PERGAMON PRESS
Headington Hill Hall, Oxford *Oxford* 64881

PITMAN, SIR ISAAC & SONS LTD.
Parker Street, Kingsway, London W.C.2. *Holborn* 876.

REDIFON LTD.
Broomhill Road, London S.W.18. *Vandyke* 7281
Gatwick Road, Crawley, Sussex. *Crawley* 28311

RESEARCH & ENGINEERING CONTROLS LTD.
9 Old Bridge St., Kingston-on-Thames,
Surrey. *Kingston* 6220-9

ROBERT RILEY LTD.
Milkstone, Spring Works, Rochdale. *Rochdale* 2237

ROLLS-ROYCE LTD.
Derby. *Derby* 42424
14-15 Conduit Street, London W.1. *Mayfair* 6201

ROTAX LTD.
Willesden Junction, London N.W.10. *Elgar* 7777

SAMPSON LOW
16 Maddox Street, London, W.1. *Mayfair* 1064

SHELL AVIATION SERVICES, SHELL-MEX & B.P. LTD.
Shell-Mex House, Strand, London W.C.2. *Temple Bar* 1234

SMITHS AVIATION DIVISION
Kelvin House, Wembley Park Drive,
Wembley, Middx. *Wembley* 8833

SPERRY GYROSCOPE CO. LTD.
Great West Road, Brentford, Middlesex. *Isleworth* 1241

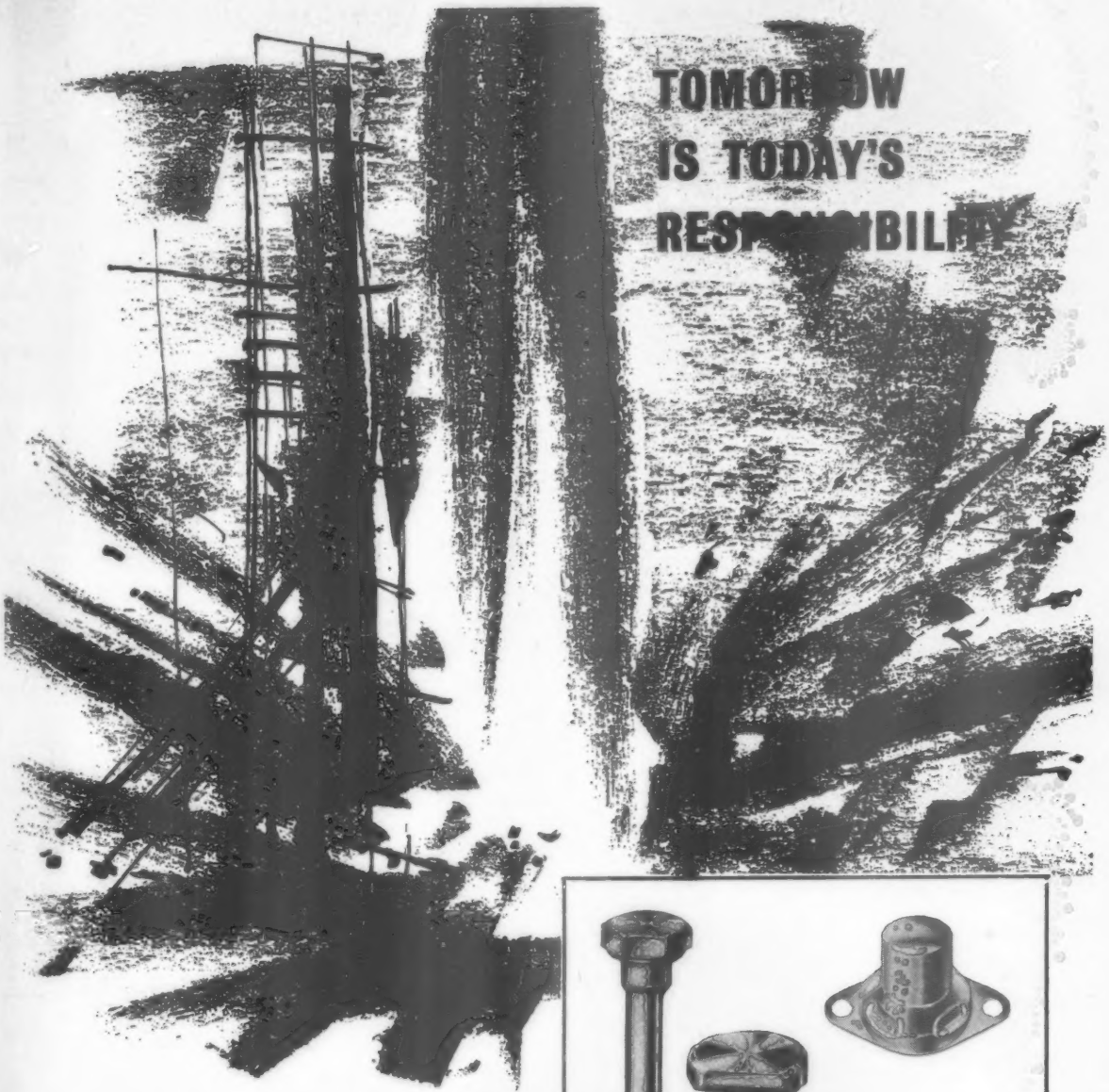
TEDDINGTON AIRCRAFT CONTROLS LTD.
Merthyr Tydfil, South Wales. *Merthyr Tydfil* 3281
London Airport Office: Colnbrook By-Pass
West Drayton, Middlesex. *Colnbrook* 2202

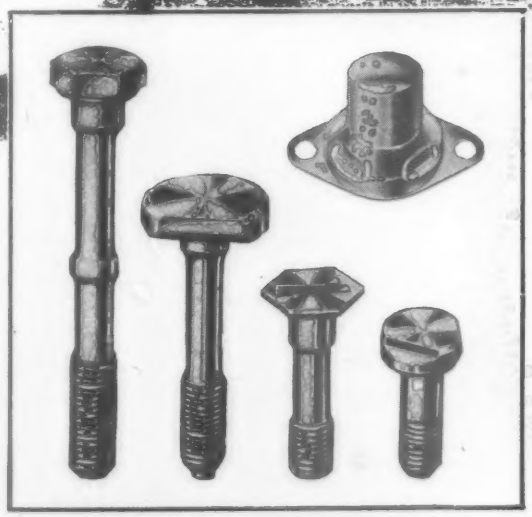
ULTRA ELECTRONICS LTD
Western Avenue, Acton, London, W.3. *Acorn* 3434

UNBRAKO SOCKET SCREW CO. LTD.
Burnaby Road, Coventry. *Coventry* 89471

VICKERS-ARMSTRONGS (AIRCRAFT) LTD.
Vickers House, Broadway, Westminster,
London, S.W.1. *Abbey* 7777
Weybridge Works, Weybridge, Surrey. *Weybridge* 5353
Supermarine Works, South Marston,
Swindon, Wilts. *Swindon* 3451

WESTLAND AIRCRAFT LTD.
Yeovil, Somerset. *Yeovil* 1100





The men of Unbrako's Advanced Design Division are visionaries with both feet on the ground, engineers with their gaze on the stars. You need not only skill and experience for this job, but imagination, too. The task of Unbrako AD is to find the answer before anyone thinks of the question, to provide today fastenings which will enable people to plan realistically for tomorrow.

UNBRAKO-AD

THE ADVANCED DESIGN DIVISION OF UNBRAKO

UNBRAKO SOCKET SCREW CO LTD COVENTRY TEL: 88722

PRINTED BY THE LEWES PRESS, WIGHTMAN & CO. LTD., LEWES, SUSSEX, ENGLAND, AND PUBLISHED BY THE ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, LONDON W.1, ENGLAND

1765